US009849807B2

(12) **United States Patent**
Mathews, Jr. et al.

(10) **Patent No.: US 9,849,807 B2**
(45) **Date of Patent: *Dec. 26, 2017**

(54) **SYSTEM AND METHOD FOR DETERMINING OPERATIONAL GROUP ASSIGNMENTS OF VEHICLES IN A VEHICLE SYSTEM**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventors: **Harry Kirk Mathews, Jr.**, Niskayuna, NY (US); **Dan Dai**, Niskayuna, NY (US); **James Brooks**, Niskayuna, NY (US)

(73) Assignee: **General Electric Company**, Niskayuna, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/248,961**

(22) Filed: **Aug. 26, 2016**

(65) **Prior Publication Data**

US 2016/0362022 A1 Dec. 15, 2016

Related U.S. Application Data

(63) Continuation-in-part of application No. 14/631,495, filed on Feb. 25, 2015, now Pat. No. 9,453,735, which

(Continued)

(51) **Int. Cl.**

B60L 15/38 (2006.01)
B60L 15/20 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***B60L 15/38*** (2013.01); ***B60L 15/20*** (2013.01); ***B60L 15/2009*** (2013.01);

(Continued)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,702,291 A 10/1987 Engle
6,972,670 B2 12/2005 LaDuc et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CA 2454739 C 9/2011

OTHER PUBLICATIONS

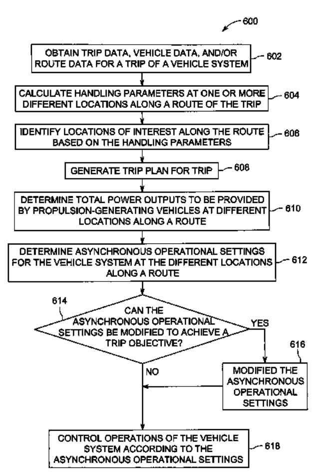
Intelligent Rail Transportation (ICIRT), 2013 IEEE International Conference; "Energy-Efficient Operation of Heavy Haul Trains in an MPC Framework", Lijun Zhang Qi Li; Xiangtao Zhuan; Aug. 30, 2013-Sep. 1, 2013; pp. 105-110.

Primary Examiner — Russell Frejd
(74) *Attorney, Agent, or Firm* — Nitin N. Joshi

(57) **ABSTRACT**

A vehicle control system includes one or more processors configured to assign plural vehicles to different groups in one or more vehicle systems for travel along one or more routes. The one or more processors also are configured to determine trip plans for the different groups. The trip plans designate different operational settings of the vehicles in the different groups at different locations along one or more routes during movement of the one or more vehicle systems along the one or more routes. The one or more processors also are configured to modify one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems. The trip plans for the different groups of the vehicles are interdependent upon each other.

20 Claims, 16 Drawing Sheets



Related U.S. Application Data

is a continuation-in-part of application No. 14/319,885, filed on Jun. 30, 2014, now Pat. No. 9,002,547, which is a continuation-in-part of application No. 13/729,298, filed on Dec. 28, 2012, now Pat. No. 8,838,302.

(51) **Int. Cl.**

B60L 15/36	(2006.01)
G05D 1/02	(2006.01)
B61C 17/12	(2006.01)
G01C 21/26	(2006.01)
G08G 1/00	(2006.01)
G06F 17/10	(2006.01)
B61L 3/00	(2006.01)
B61L 3/16	(2006.01)
B61L 15/00	(2006.01)
B61L 27/00	(2006.01)
B61L 25/02	(2006.01)

(52) **U.S. Cl.**

CPC ***B60L 15/2018*** (2013.01); ***B60L 15/2045*** (2013.01); ***B60L 15/36*** (2013.01); ***B61C 17/12*** (2013.01); ***B61L 3/006*** (2013.01); ***B61L 3/008*** (2013.01); ***B61L 3/16*** (2013.01); ***B61L 15/0081*** (2013.01); ***B61L 27/0027*** (2013.01); ***G01C 21/26*** (2013.01); ***G05D 1/0293*** (2013.01); ***G06F 17/10*** (2013.01); ***G08G 1/00*** (2013.01); *B60L 2200/26* (2013.01); *B60L 2240/642* (2013.01); *B60L 2240/645* (2013.01); *B60L 2240/80* (2013.01); *B60L 2270/12* (2013.01); *B61L 15/0027* (2013.01); *B61L 25/025* (2013.01); *Y02T 10/7283* (2013.01); *Y02T 10/7291* (2013.01); *Y02T 30/10* (2013.01); *Y02T 90/16* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,944,081	B2	5/2011	Donnelly
8,157,218	B2	4/2012	Riley et al.
8,220,572	B2	7/2012	Donnelly
8,239,078	B2	8/2012	Siddappa et al.
8,428,798	B2	4/2013	Kull
8,589,001	B2	11/2013	Siddappa et al.
8,838,302	B2	9/2014	Kumar et al.
2009/0090818	A1	4/2009	Kumar
2013/0131909	A1	5/2013	Cooper
2014/0263860	A1	9/2014	Iden et al.
2014/0316618	A1	10/2014	Matthews, Jr. et al.

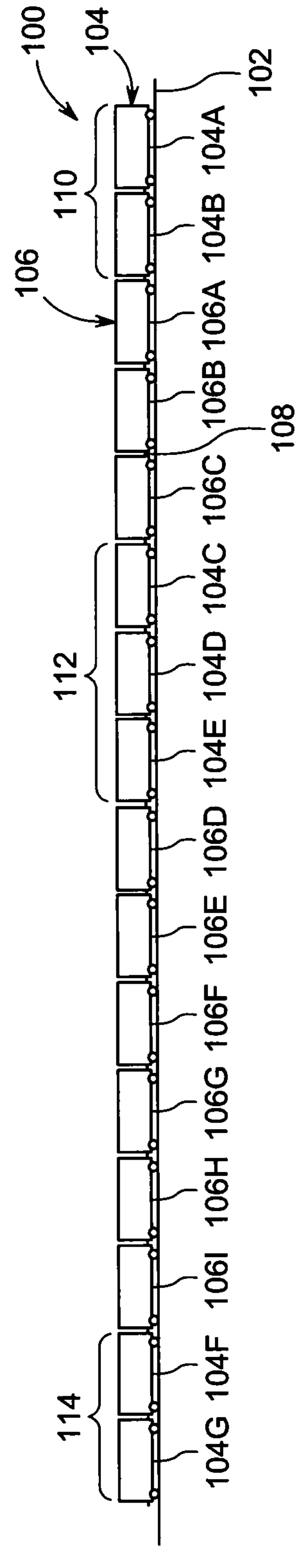

100
104
102
110
104A
104B
106
106A
106B
108
106C
112
104C
104D
104E
106D
106E
106F
106G
106H
106I
114
104F
104G

FIG. 1

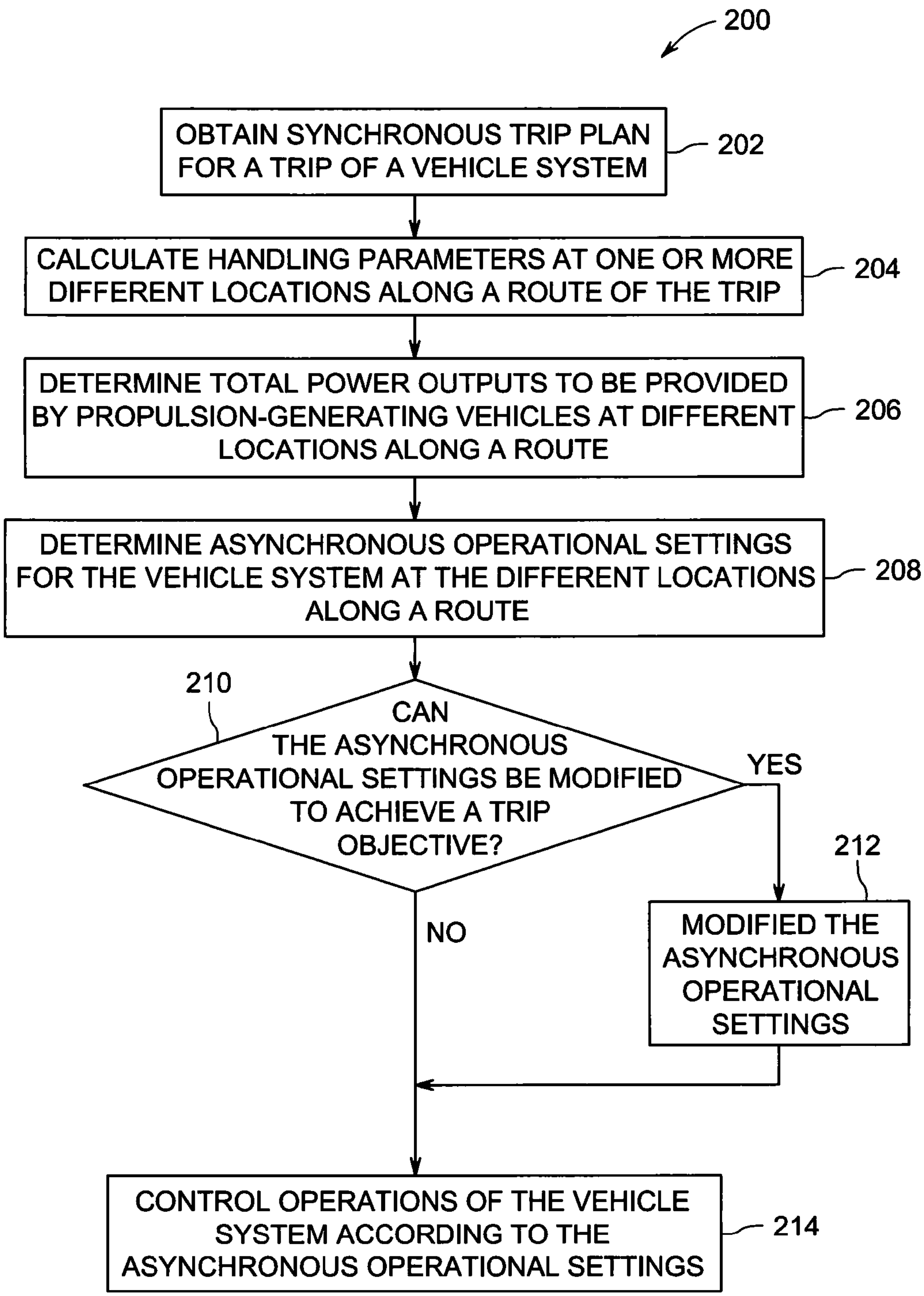
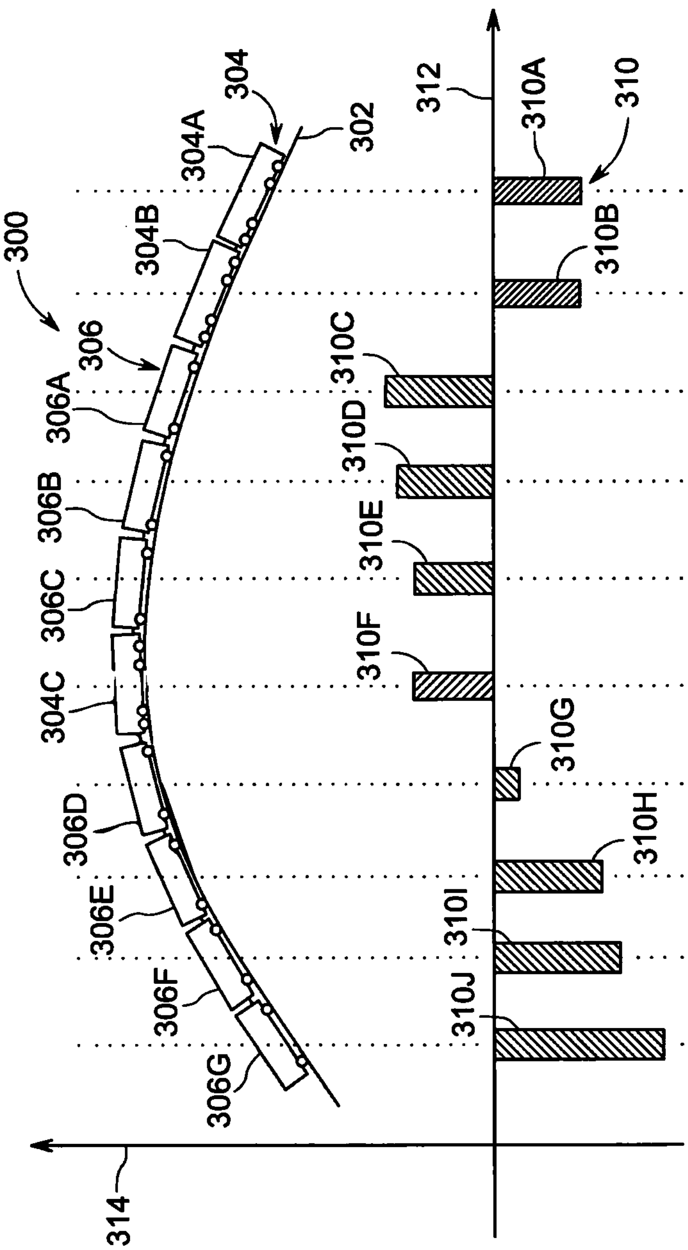

200
OBTAIN SYNCHRONOUS TRIP PLAN FOR A TRIP OF A VEHICLE SYSTEM
202
CALCULATE HANDLING PARAMETERS AT ONE OR MORE DIFFERENT LOCATIONS ALONG A ROUTE OF THE TRIP
204
DETERMINE TOTAL POWER OUTPUTS TO BE PROVIDED BY PROPULSION-GENERATING VEHICLES AT DIFFERENT LOCATIONS ALONG A ROUTE
206
DETERMINE ASYNCHRONOUS OPERATIONAL SETTINGS FOR THE VEHICLE SYSTEM AT THE DIFFERENT LOCATIONS ALONG A ROUTE
208
210
CAN THE ASYNCHRONOUS OPERATIONAL SETTINGS BE MODIFIED TO ACHIEVE A TRIP OBJECTIVE?
YES
212
MODIFIED THE ASYNCHRONOUS OPERATIONAL SETTINGS
NO
CONTROL OPERATIONS OF THE VEHICLE SYSTEM ACCORDING TO THE ASYNCHRONOUS OPERATIONAL SETTINGS
214

FIG. 2



300
302
304
304A
304B
304C
306
306A
306B
306C
306D
306E
306F
306G
310
310A
310B
310C
310D
310E
310F
310G
310H
310I
310J
312
314

FIG. 3

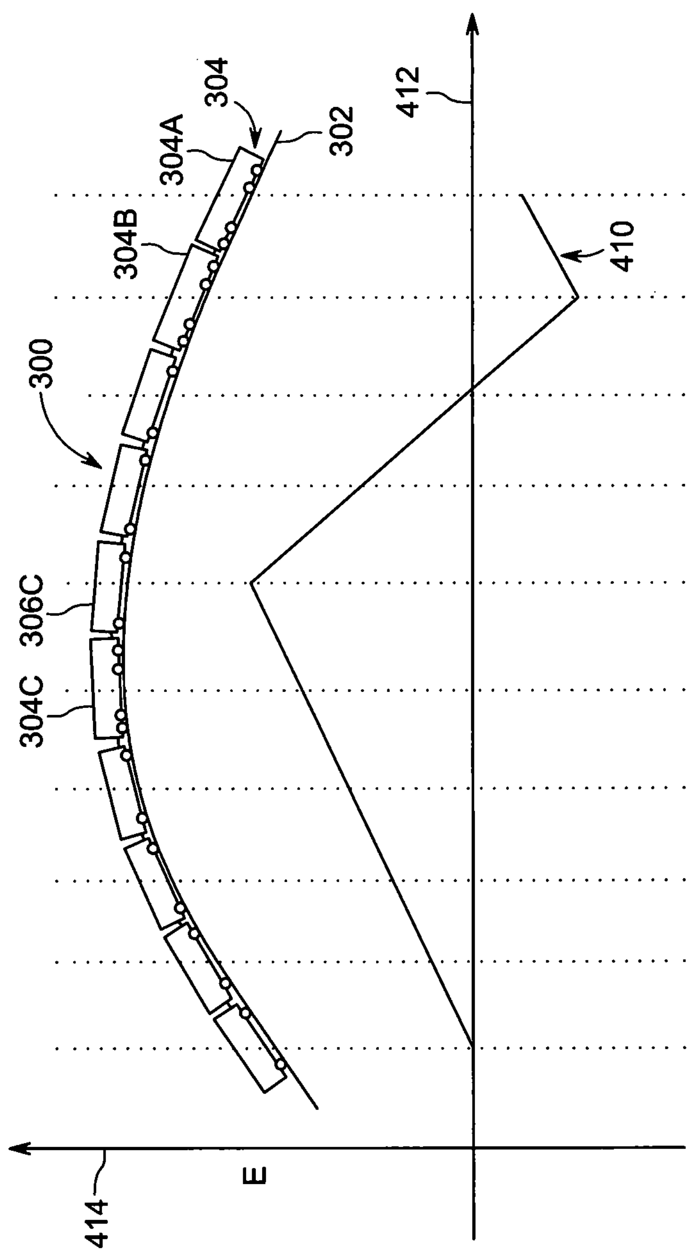


FIG. 4

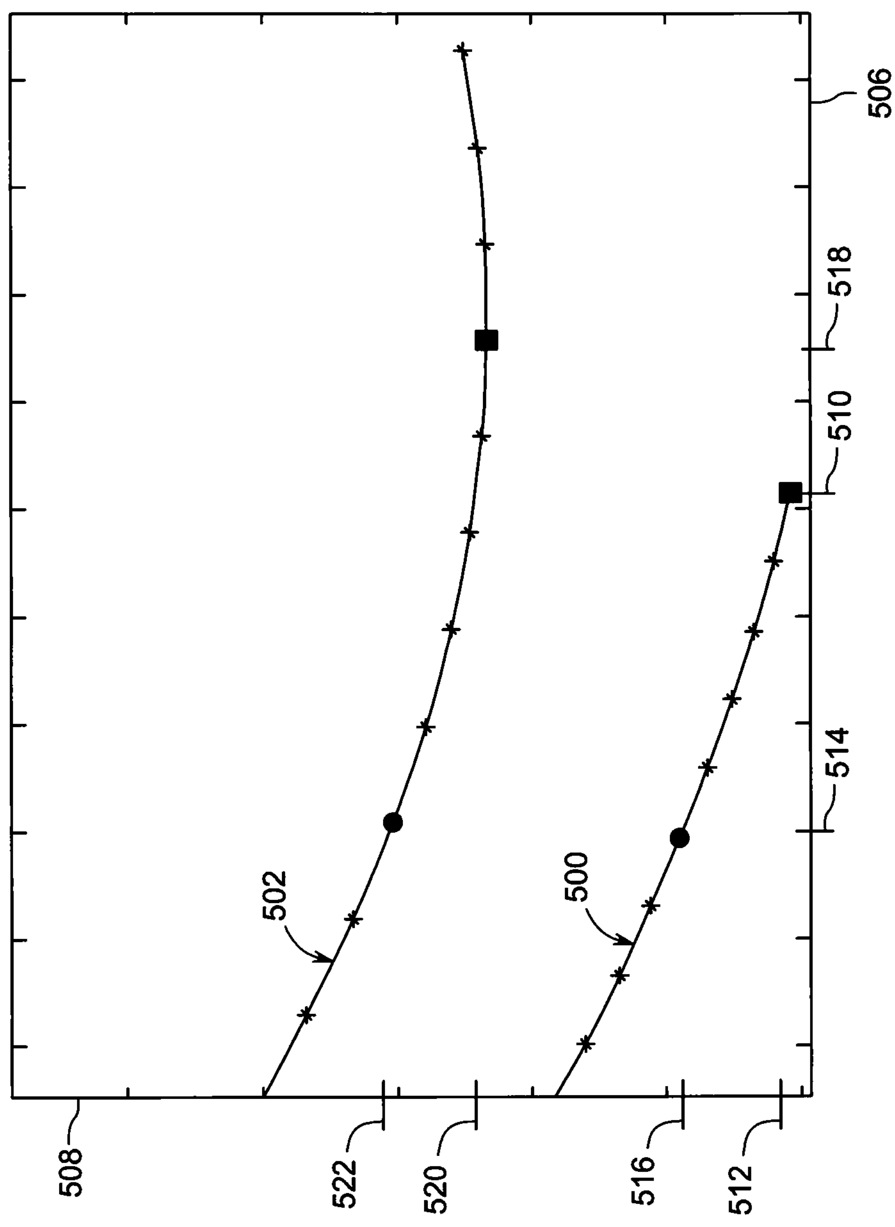


FIG. 5

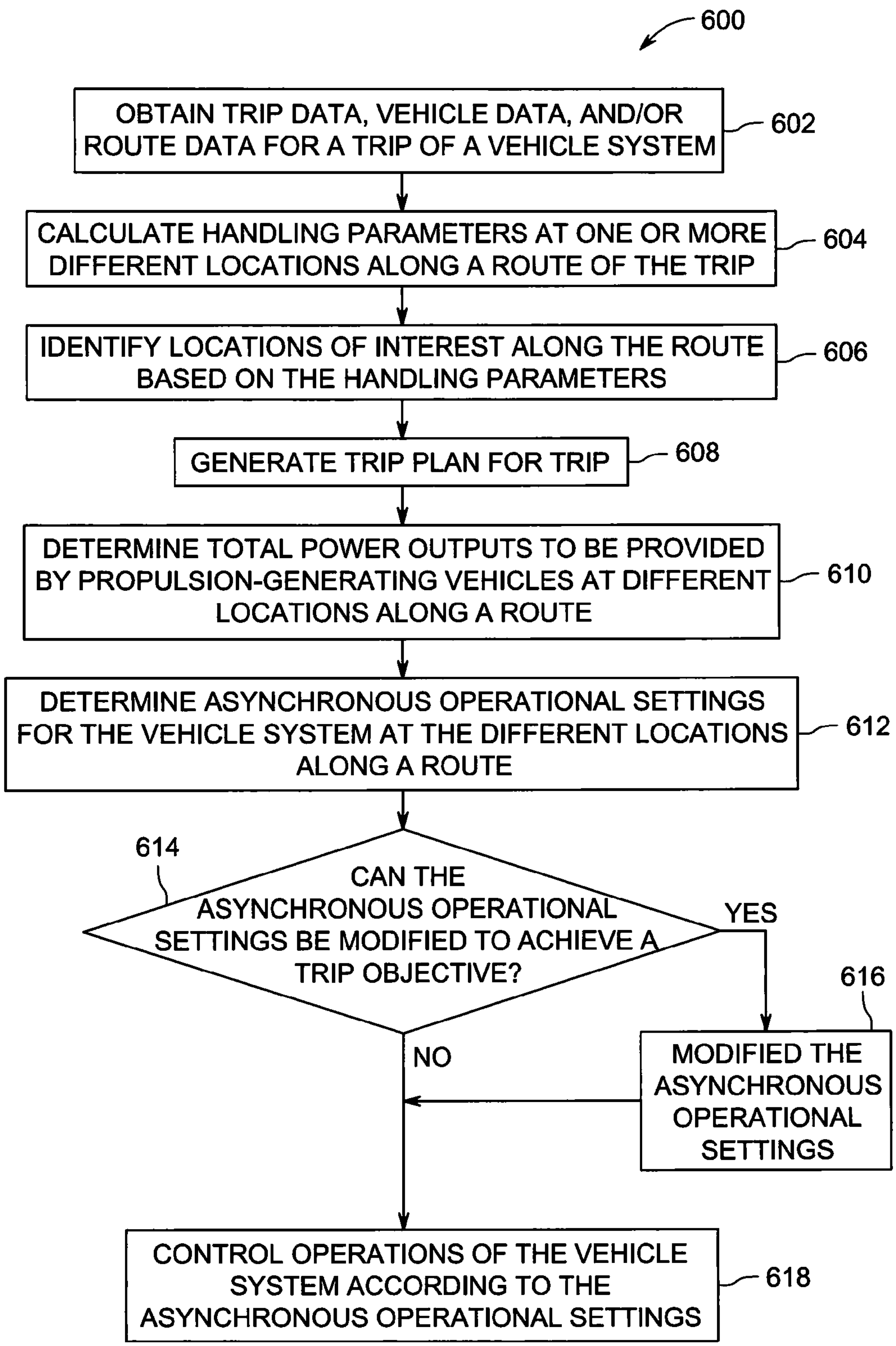

600
OBTAIN TRIP DATA, VEHICLE DATA, AND/OR ROUTE DATA FOR A TRIP OF A VEHICLE SYSTEM
602
CALCULATE HANDLING PARAMETERS AT ONE OR MORE DIFFERENT LOCATIONS ALONG A ROUTE OF THE TRIP
604
IDENTIFY LOCATIONS OF INTEREST ALONG THE ROUTE BASED ON THE HANDLING PARAMETERS
606
GENERATE TRIP PLAN FOR TRIP
608
DETERMINE TOTAL POWER OUTPUTS TO BE PROVIDED BY PROPULSION-GENERATING VEHICLES AT DIFFERENT LOCATIONS ALONG A ROUTE
610
DETERMINE ASYNCHRONOUS OPERATIONAL SETTINGS FOR THE VEHICLE SYSTEM AT THE DIFFERENT LOCATIONS ALONG A ROUTE
612
614
CAN THE ASYNCHRONOUS OPERATIONAL SETTINGS BE MODIFIED TO ACHIEVE A TRIP OBJECTIVE?
YES
NO
616
MODIFIED THE ASYNCHRONOUS OPERATIONAL SETTINGS
CONTROL OPERATIONS OF THE VEHICLE SYSTEM ACCORDING TO THE ASYNCHRONOUS OPERATIONAL SETTINGS
618

FIG. 6

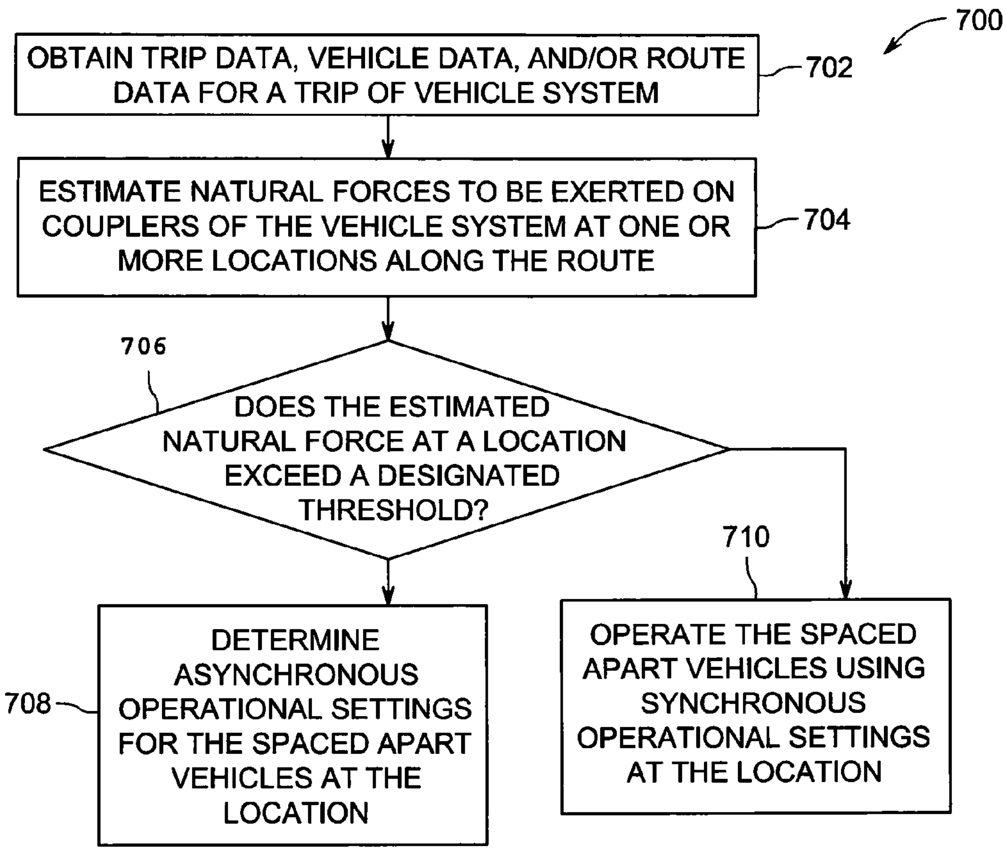

700
OBTAIN TRIP DATA, VEHICLE DATA, AND/OR ROUTE DATA FOR A TRIP OF VEHICLE SYSTEM
702
ESTIMATE NATURAL FORCES TO BE EXERTED ON COUPLERS OF THE VEHICLE SYSTEM AT ONE OR MORE LOCATIONS ALONG THE ROUTE
704
706
DOES THE ESTIMATED NATURAL FORCE AT A LOCATION EXCEED A DESIGNATED THRESHOLD?
710
708
DETERMINE ASYNCHRONOUS OPERATIONAL SETTINGS FOR THE SPACED APART VEHICLES AT THE LOCATION
OPERATE THE SPACED APART VEHICLES USING SYNCHRONOUS OPERATIONAL SETTINGS AT THE LOCATION

FIG. 7

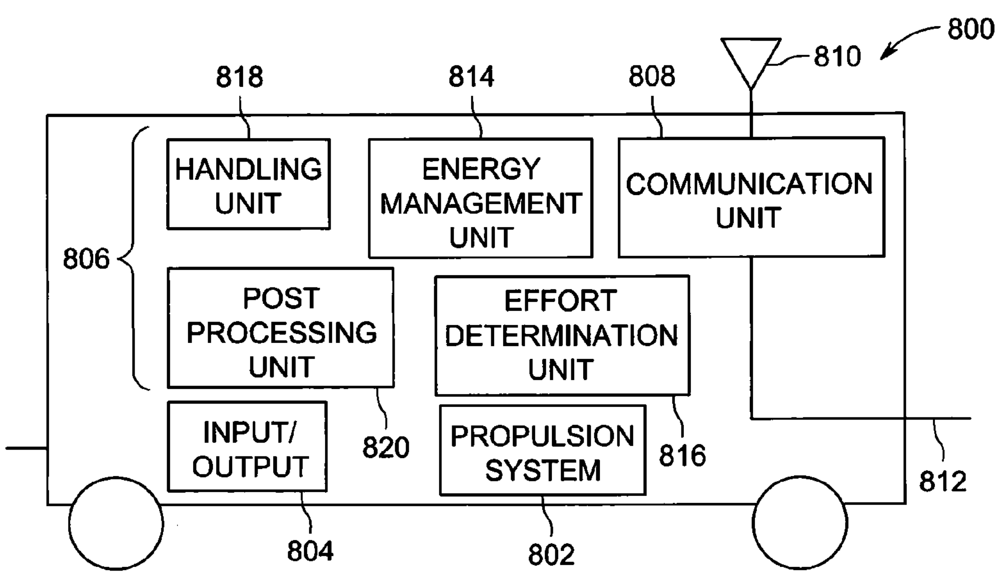

800
810
818
814
808
HANDLING UNIT
ENERGY MANAGEMENT UNIT
COMMUNICATION UNIT
806
POST PROCESSING UNIT
EFFORT DETERMINATION UNIT
INPUT/ OUTPUT
820
PROPULSION SYSTEM
816
812
804
802

FIG. 8

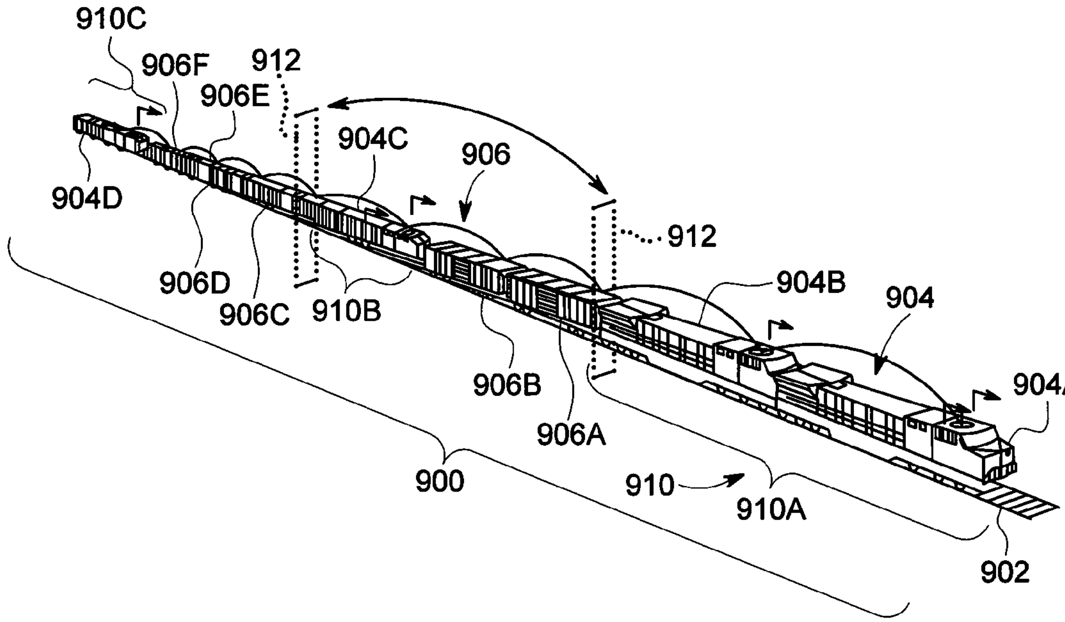

910C
906F
906E
912
904C
906
904D
912
906D
904B
904
906C
910B
906B
904A
906A
900
910
910A
902

FIG. 9

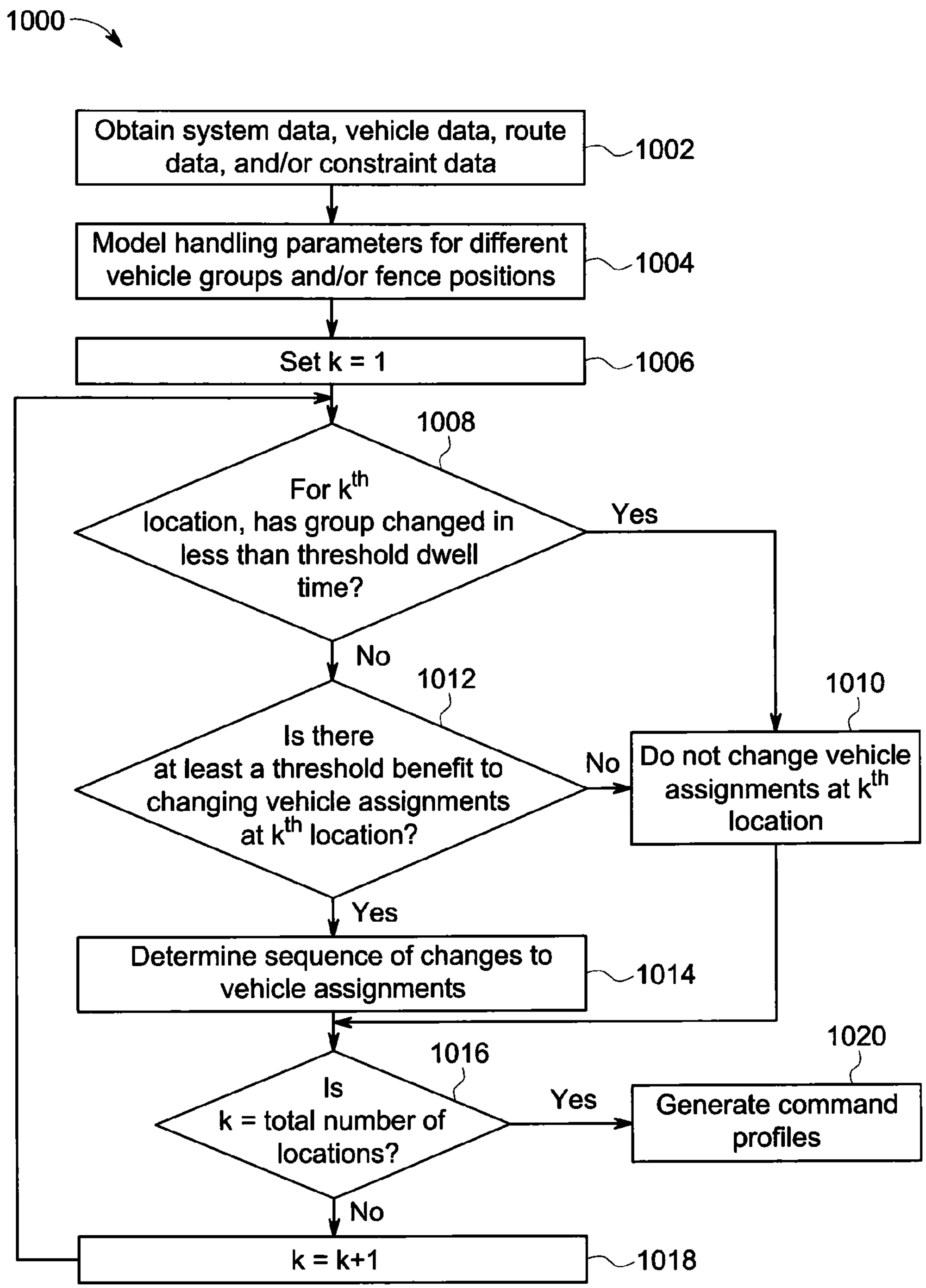

1000
Obtain system data, vehicle data, route data, and/or constraint data
1002
Model handling parameters for different vehicle groups and/or fence positions
1004
Set k = 1
1006
1008
For k^th location, has group changed in less than threshold dwell time?
Yes
No
1012
Is there at least a threshold benefit to changing vehicle assignments at k^th location?
No
1010
Do not change vehicle assignments at k^th location
Yes
Determine sequence of changes to vehicle assignments
1014
1016
Is k = total number of locations?
Yes
1020
Generate command profiles
No
k = k+1
1018

FIG. 10

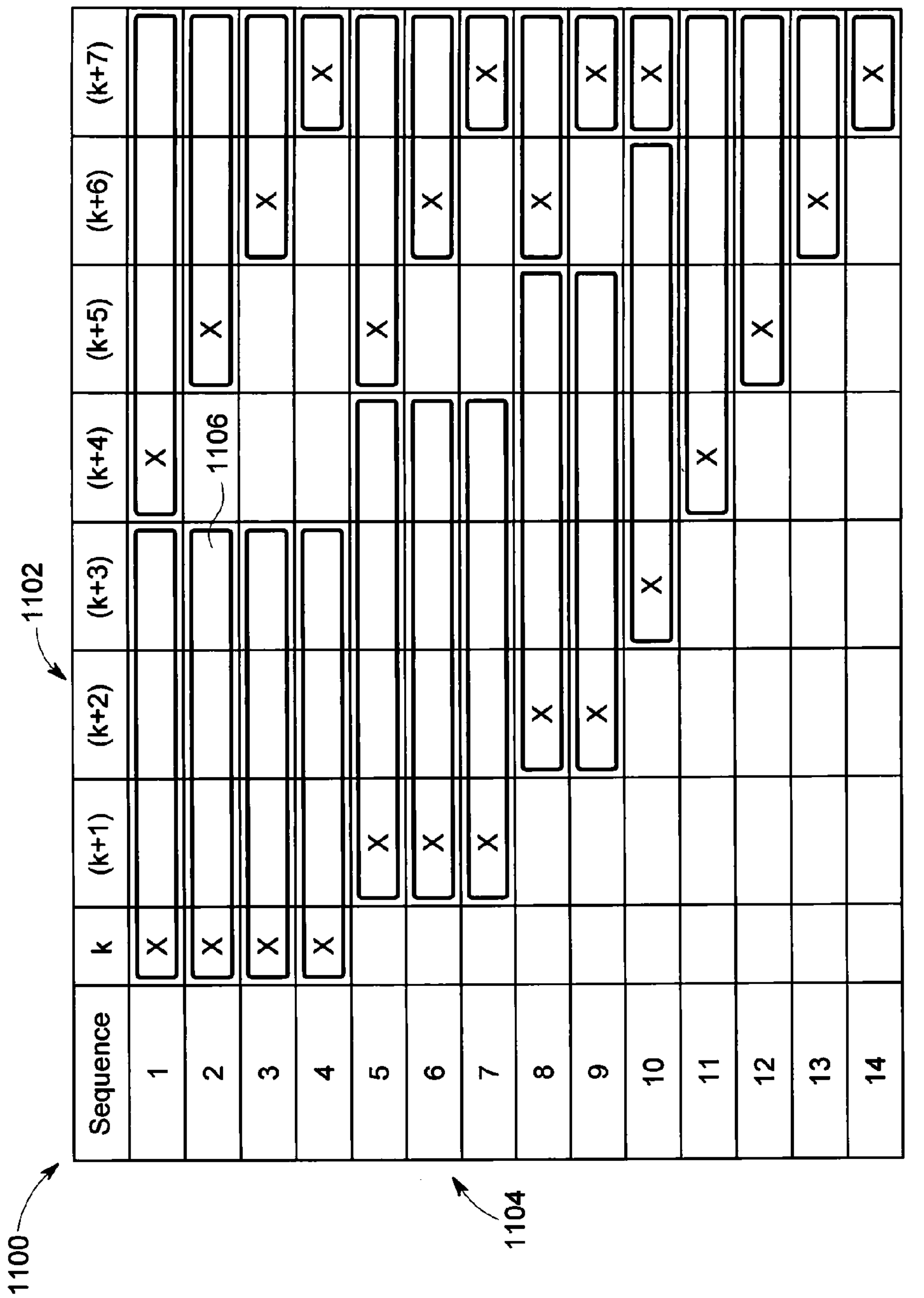

1100
1102
1104
1106
Sequence
k
(k+1)
(k+2)
(k+3)
(k+4)
(k+5)
(k+6)
(k+7)
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FIG. 11

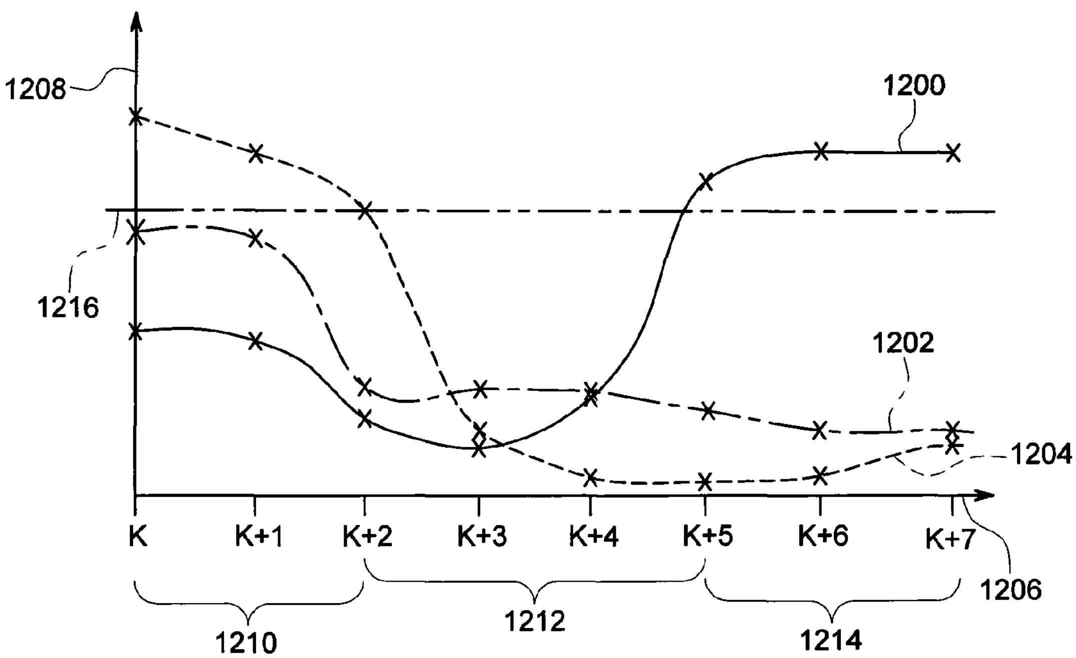

1208
1200
1216
1202
1204
K
K+1
K+2
K+3
K+4
K+5
K+6
K+7
1206
1210
1212
1214

FIG. 12

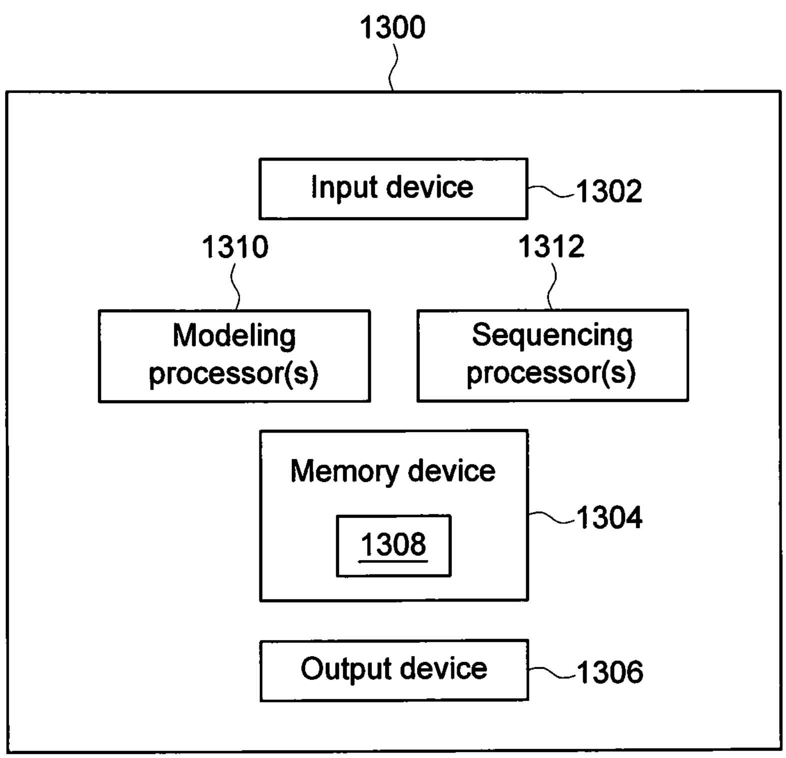

1300
Input device
1302
1310
1312
Modeling processor(s)
Sequencing processor(s)
Memory device
1308
1304
Output device
1306

FIG. 13

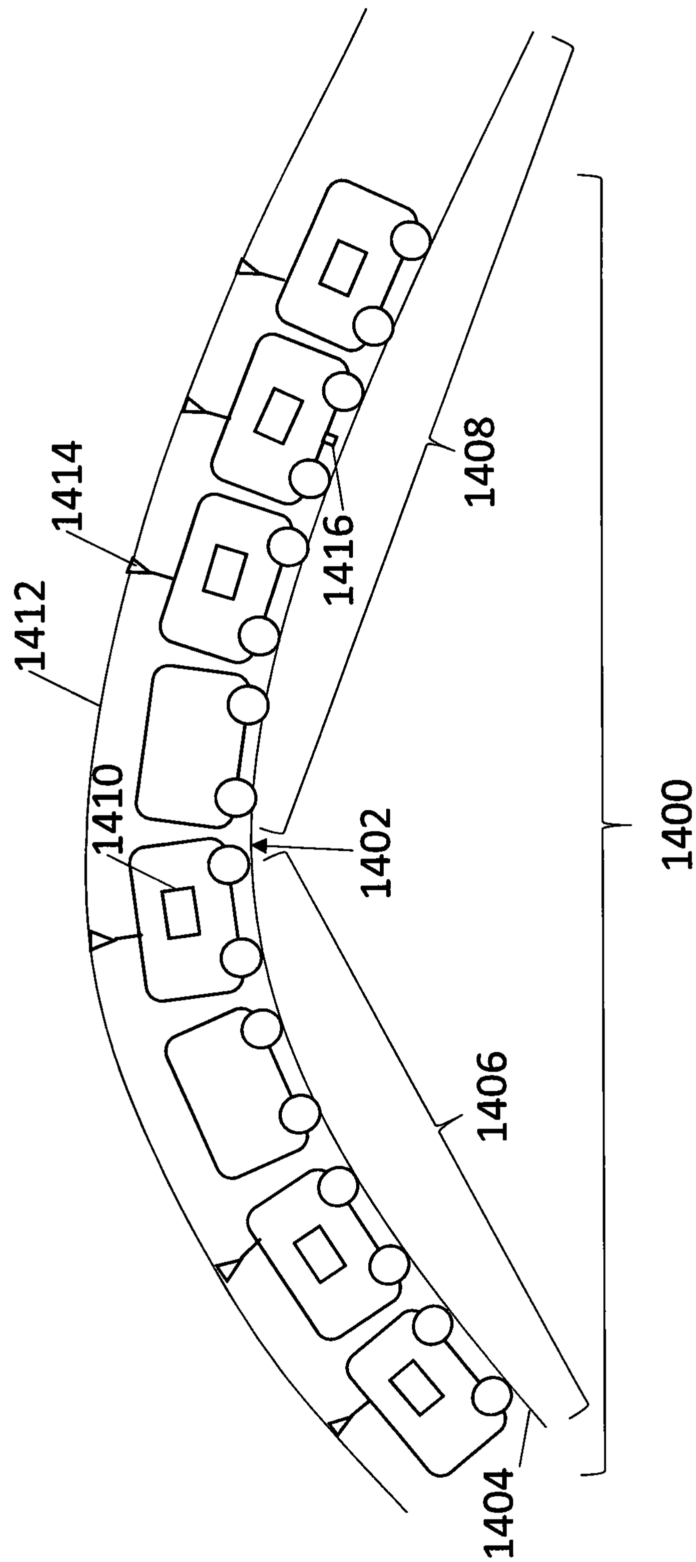


FIG. 14

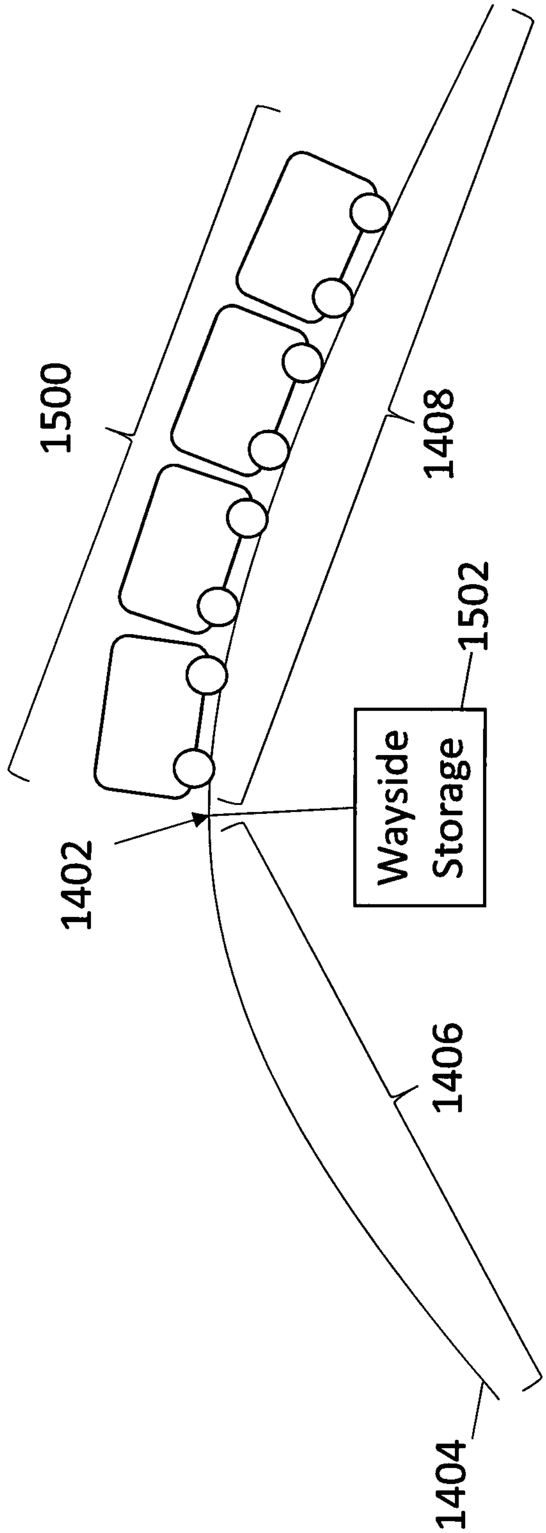


FIG. 15

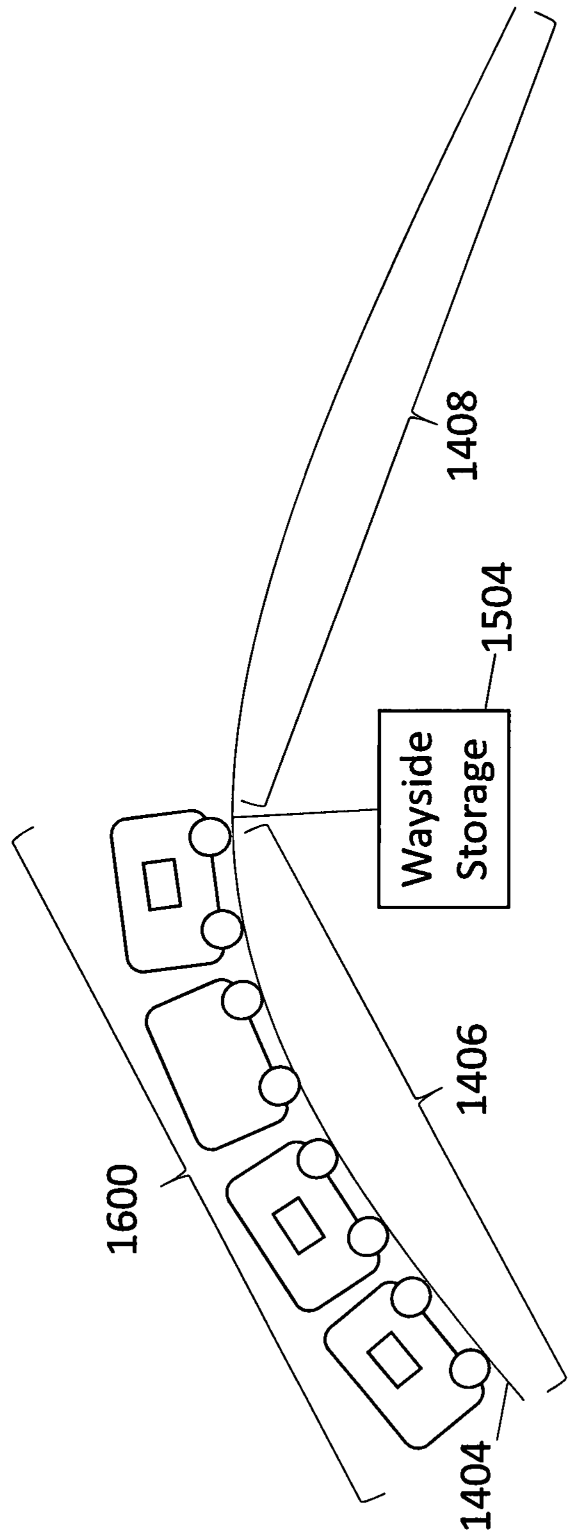


FIG. 16

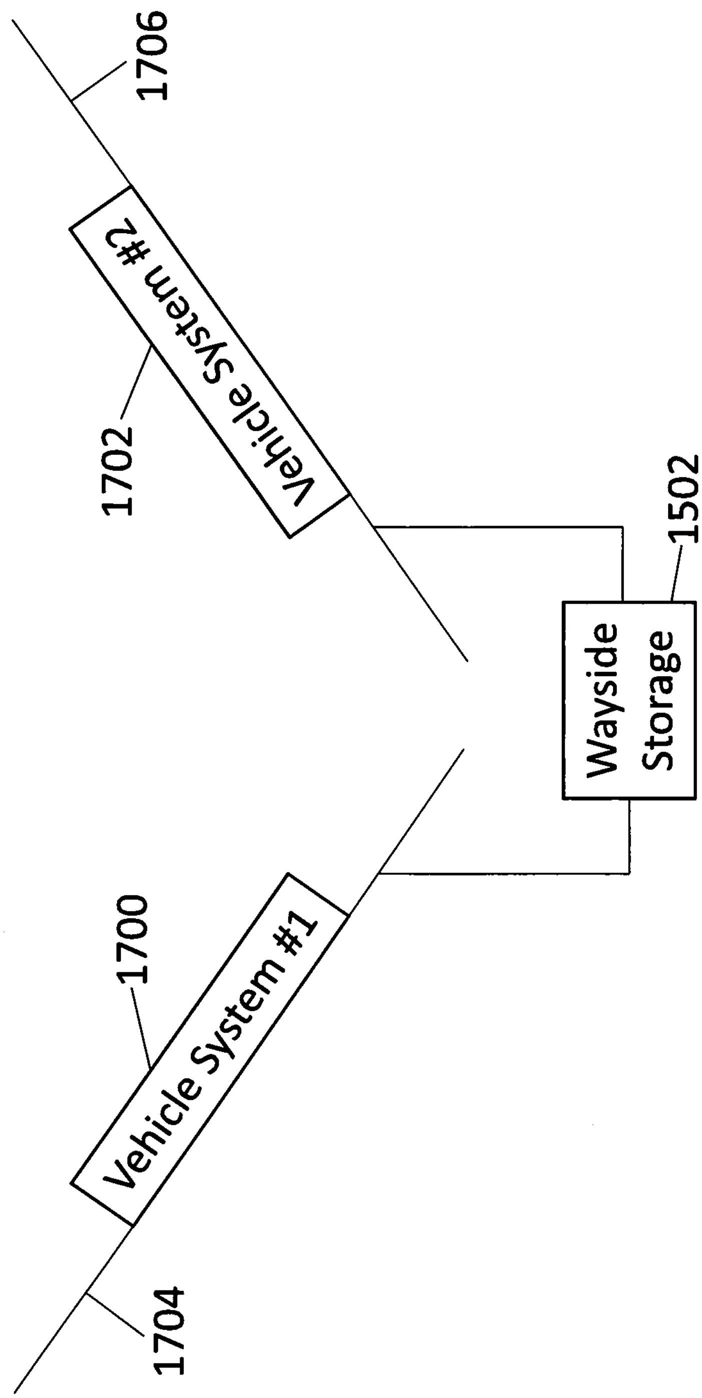

1706
Vehicle System #2
1702
1502
Wayside
Storage
1700
Vehicle System #1
1704

FIG. 17

SYSTEM AND METHOD FOR DETERMINING OPERATIONAL GROUP ASSIGNMENTS OF VEHICLES IN A VEHICLE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 14/631,495, which was filed on 25 Feb. 2015, now U.S. Pat. No. 9,453,735, issued Sep. 27, 2016 (the "'495 Application"), and which is a continuation-in-part of U.S. patent application Ser. No. 14/319,885, which was filed on 30 Jun. 2014, now U.S. Pat. No. 9,002,547 issued Apr. 7, 2015 (the "'885 Application"). The '885 Application is a continuation-in-part of U.S. patent application Ser. No. 13/729,298, which was filed on 28 Dec. 2012, now U.S. Pat. No. 8,838,302 issued Sep. 16, 2014 (the "'298 Application"). The entire disclosures of the '495 Application, the '885 Application, and the '298 Application are incorporated herein by reference.

FIELD

Embodiments of the subject matter disclosed herein relate to determining plans for controlling operations of vehicle systems.

BACKGROUND

Some known vehicle systems include multiple vehicles connected together so that the vehicles can travel together. Such vehicle systems can be referred to as consists. Some vehicle systems can include multiple consists that each includes powered or propulsion-generating vehicles providing propulsive force.

The operations of the propulsion-generating vehicles can be coordinated with each other by remotely controlling some propulsion-generating vehicles from another propulsion-generating vehicle in the vehicle system. For example, distributed power (DP) control of the propulsion-generating vehicles may involve propulsion-generating vehicles in the vehicle system being controlled to have the same throttle and/or brake settings at the same time. Alternatively, the propulsion-generating vehicles in a first consist of the vehicle system may operate with the same throttle or brake settings while the propulsion-generating vehicles in a different, second consist of the same vehicle system operate with throttle or brake settings that are the same, but different from the settings used by the propulsion-generating vehicles in the first consist. In the terminology of current DP systems, it is said that a fence is set up between the first and second consists.

Because vehicle systems may be very long, different segments of the vehicle systems may experience different grades and/or curvatures in a route at the same time. Using the same throttle or brake settings for multiple propulsion-generating vehicles traveling over different grades and/or curvatures can result in undesirable forces on couplers of the propulsion-generating vehicles that are located between the propulsion-generating vehicles and/or undesirable movements of vehicles. For example, when cresting a hill, using the same throttle settings on all propulsion-generating vehicles can cause the vehicles located at or near the apex of the hill to experience relatively large tensile forces, can cause the vehicles on the downward slope of the hill to move faster than and away from other vehicles at or near the apex,

and/or can cause the vehicles on the upward slope of the hill to move slower than and away from the other vehicles at or near the apex. These forces and/or movements can damage the couplers connecting the vehicles, cause the vehicle system to break apart, and/or generally degrade handling of the vehicle system as experienced by an operator of the vehicle system.

BRIEF DESCRIPTION

In one embodiment, a system (e.g., a vehicle control system) includes one or more processors configured to assign plural vehicles to different groups in one or more vehicle systems for travel along one or more routes. The one or more processors also are configured to determine trip plans for the different groups of the vehicles. The trip plans designate different operational settings of the vehicles in the different groups at different locations (and/or different times and/or difference distances) along one or more routes during movement of the one or more vehicle systems along the one or more routes. The one or more processors also are configured to modify one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems. The trip plans for the different groups of the vehicles are interdependent upon each other.

In one embodiment, a method (e.g., for controlling movement of a vehicle system) includes assigning plural vehicles to different groups in one or more vehicle systems for travel along one or more routes and determining trip plans for the different groups of the vehicles. The trip plans designate different operational settings of the vehicles in the different groups at different locations (and/or different times and/or different distances) along one or more routes during movement of the one or more vehicle systems along the one or more routes. The method also includes modifying one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems. The trip plans for the different groups of the vehicles can be interdependent upon each other.

In one embodiment, a method (e.g., for determining operational settings for a vehicle system having multiple vehicles connected with each other by couplers to travel along a route) includes identifying total power outputs to be provided by propulsion-generating vehicles of the vehicles in the vehicle system. The total power outputs are determined for different locations of the vehicle system along the route. The method also includes calculating parameters of the vehicle system at one or more of the different locations along the route. The method also includes determining asynchronous operational settings for the propulsion-generating vehicles at the different locations along the route. The asynchronous operational settings represent different operational settings for the propulsion-generating vehicles that cause the propulsion-generating vehicles to provide at least the total power outputs at the respective different locations while changing the parameters of the vehicle system to one or more designated values at the different locations along the route. As one example, the different operational settings may be different notch settings of throttles of the different vehicles in the vehicle system. Due to differences in the vehicles, different notch settings on different vehicles may result in the vehicles individually providing the same amount of power output. Alternatively, the vehicles may provide different power outputs when using the same throttle settings. The method further includes communicating the asynchronous operational settings to the propulsion-generating vehicles in order to cause the propulsion-generating vehicles to implement the asynchronous operational settings at the different locations.

In one embodiment, a system (e.g., a control system for a vehicle system) includes an effort determination unit configured to identify total power outputs to be provided by a vehicle system that includes multiple vehicles connected with each other by couplers to travel along a route. The effort determination unit also is configured to identify the total power outputs to be provided by propulsion-generating vehicles of the vehicles in the vehicle system at different locations of the vehicle system along the route. The system includes a handling unit configured to calculate parameters of the vehicle system at one or more of the different locations along the route. The system includes a processing unit configured to determine asynchronous operational settings for the propulsion-generating vehicles at the different locations along the route. The asynchronous operational settings represent different operational settings for the propulsion-generating vehicles that cause the propulsion-generating vehicles to provide at least the total power outputs at the respective different locations while changing the parameters of the vehicle system to one or more designated values at the different locations along the route. The asynchronous operational settings are configured to be communicated to the propulsion-generating vehicles in order to cause the propulsion-generating vehicles to implement the asynchronous operational settings at the different locations.

In one embodiment, a method (e.g., for determining operational settings for a vehicle system having two or more propulsion-generating vehicles coupled with each other by one or more non-propulsion generating vehicles) includes obtaining route data and vehicle data. The route data is representative of one or more grades of a route at one or more locations along the route that is to be traveled by the vehicle system. The vehicle data is representative of a size of the one or more non-propulsion generating vehicles disposed between the propulsion-generating vehicles. The method also includes calculating one or more estimated natural forces that are to be exerted on couplers connected with the one or more non-propulsion generating vehicles of the vehicle system at the one or more locations along the route. The one or more estimated natural forces are based on the size of the one or more non-propulsion generating vehicles and the one or more grades of the route at the one or more locations along the route. The method also includes determining asynchronous operational settings to be implemented by the two or more propulsion-generating vehicles at the one or more locations along the route. Implementing the asynchronous operational settings by the two or more propulsion-generating vehicles reduces one or more actual natural forces that are actually exerted on the couplers to forces that are smaller than the one or more estimated natural forces when the vehicle system travels over the one or more locations along the route.

In another embodiment, a method (e.g., for determining dynamically changing distributions of vehicles in a vehicle system) includes determining parameters of a vehicle system that includes plural vehicles operably coupled with each other to travel along a route during a trip. The parameters are determined for different distributions of the vehicles among different groups of the vehicles at different potential change points along the route. In one aspect, changing a distribution of the vehicles among different groups includes logically changing which group one or more vehicles are assigned to without actually physically moving the one or more vehicles. This may be done dynamically en-route or statically at the beginning of a trip. Alternatively, one or more embodiments described herein can be to determine different distributions of the vehicles among different groups that does involve physically moving the vehicles relative to each other to position the vehicles with each other in the respective groups. While this would typically be statically at the beginning of a trip, there are cases when a vehicle may be added to the system for a portion of the trip. For example, the vehicle system may stop during travel between two locations to change locations of vehicles within the vehicle system, to add one or more vehicles to the vehicle system, and/or to remove one or more vehicles from the vehicle system.

The method also can include determining whether to change the distributions of the vehicles among the different groups at one or more of the potential change points based on the parameters that are determined and, based on determining that the distributions of the vehicles among the different groups are to change, determining a selected sequence of changes to the distributions of the vehicles among the different groups at one or more of the potential change points along the route. The method also includes generating change indices for one or more of the trip or an upcoming segment of the trip based on the selected sequence. The change indices designate one or more of times or the one or more potential change points along the route at which the distributions of the vehicles among the different groups changes. The vehicles included in a common group of the different groups have common designated operational settings while the vehicles are in the common group.

In another embodiment, a system (e.g., a planning system) includes one or more processors configured to determine parameters of a vehicle system that includes plural vehicles operably coupled with each other to travel along a route during a trip. The parameters are determined for different distributions of the vehicles among different groups of the vehicles at different potential change points along the route. The one or more processors also are configured to determine whether to change the distributions of the vehicles among the different groups at one or more of the potential change points based on the parameters that are determined and, based on determining that the distributions of the vehicles among the different groups are to change, the one or more processors are configured to determine a selected sequence of changes to the distributions of the vehicles among the different groups at one or more of the potential change points along the route. The one or more processors also are configured to generate change indices for one or more of the trip or an upcoming segment of the trip based on the selected sequence, the change indices designating one or more of times or the one or more potential change points along the route at which the distributions of the vehicles among the different groups changes. The vehicles that are included in a common group of the different groups have common designated operational settings while the vehicles are in the common group.

In another embodiment, a method (e.g., for determining asynchronous operational settings of vehicles in a vehicle system) includes obtaining route data and vehicle data. The route data is representative of one or more of grades of a route, curvatures of the route, speed limits of the route at one or more potential change points of the route that is to be traveled by a vehicle system or that is currently being traveled by the vehicle system. The vehicle system includes plural vehicles coupled with each other. The vehicle data is representative of one or more of tractive efforts of the vehicles, braking efforts of the vehicles, or sizes of the vehicles. The method also includes predicting parameters of the vehicle system at the one or more potential change points of the route based on the route data and the vehicle data, and determining asynchronous operational settings to be implemented by the vehicles at the one or more potential change points of the route based on the parameters. The asynchronous operational settings are determined by identifying a combination of the asynchronous operational settings at the one or more potential change points of the route that result in the parameters being decreased below one or more designated thresholds.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is made to the accompanying drawings in which particular embodiments and further benefits of the inventive subject matter are illustrated as described in more detail in the description below, in which:

FIG. **1** illustrates a schematic diagram of one example of a vehicle system traveling along a route;

FIG. **2** is a flowchart of one embodiment of a method for operating the vehicle system shown in FIG. **1**;

FIG. **3** illustrates coupler parameters that are estimated for a vehicle system to travel along a route in accordance with one example;

FIG. **4** illustrates terrain excitation parameters that are estimated for the vehicle system shown in FIG. **3** to travel along the route also shown in FIG. **3** in accordance with one example;

FIG. **5** illustrates two relationships between different asynchronous operational settings and a parameter at two different locations along the route **102** shown in FIG. **1** in accordance with one example;

FIG. **6** is a flowchart of another embodiment of a method for operating the vehicle system shown in FIG. **1**;

FIG. **7** is a flowchart of another embodiment of a method for operating the vehicle system shown in FIG. **1**;

FIG. **8** is a schematic diagram of one embodiment of a propulsion-generating vehicle;

FIG. **9** is a schematic illustration of another embodiment of a vehicle system;

FIG. **10** illustrates a flowchart of a method for determining command profiles and/or change indices that dynamically change group assignments of the vehicles and/or fence positions in the vehicle systems shown herein according to one embodiment;

FIG. **11** illustrates a table demonstrating possible sequences of changing the vehicle group assignments in the vehicle system according to one embodiment;

FIG. **12** illustrates examples of parameters calculated for three different vehicle group assignments or fence positions according to one embodiment;

FIG. **13** illustrates a schematic diagram of a planning system according to one embodiment;

FIG. **14** illustrates one example of a vehicle system traversing an apex in a route;

FIG. **15** illustrates a first vehicle system traveling on a downhill segment of a route;

FIG. **16** illustrates a second vehicle system traveling on an uphill segment of a route; and

FIG. **17** illustrates vehicle systems traveling on different routes according to another example.

DETAILED DESCRIPTION

FIG. **1** illustrates a schematic diagram of one example of a vehicle system **100** traveling along a route **102**. The vehicle system **100** includes several vehicles **104**, **106** operably coupled with each other. The vehicles may be mechanically coupled with each other, such as by couplers **108**. Alternatively, the vehicles may be coupled with each other without being mechanically coupled with each other. For example, the vehicles may be aerodynamically or fluidly coupled with each other when the vehicles travel sufficiently close to each other that the drag forces imparted on one or more of the vehicles (e.g., from air, wind, water, or the like), is reduced on one or more other vehicles. Marine vessels may be fluidly or aerodynamically coupled when the vessels travel close enough together such that the drag on one or more vessels from the water is reduced relative to the marine vessels traveling farther apart. Automobiles (e.g., trucks) may be fluidly or aerodynamically coupled when the automobiles travel close enough together such that the drag on one or more automobiles is reduced relative to the automobiles traveling farther apart. Optionally, the vehicles may be logically coupled with each other, such as by the vehicles communicating with each other to coordinate the individual movements of the vehicles with each other and cause the vehicles to travel together as a vehicle system along a route. Two vehicles **104** and/or **106** may be directly connected with each other when no other vehicle **104** or **106** is disposed between the directly connected vehicles **104** and/or **106**. Two vehicles **104** and/or **106** may be indirectly connected or interconnected with each other when one or more other vehicles **104** and/or **106** are disposed between and connected with the interconnected vehicles **104** and/or **106**.

The vehicles **104** (e.g., vehicles **104**A-G) represent propulsion-generating vehicles, such as vehicles capable of generating propulsive force to propel the vehicle system **100** along the route **102**. Examples of propulsion-generating vehicles **106** include locomotives, other off-highway vehicles (e.g., vehicles that are not designed for or permitted to travel on public roadways), automobiles (e.g., vehicles that are designed for traveling on public roadways), marine vessels, and the like. In one embodiment, the vehicles **104** represent locomotives and the vehicles **106** represent rail cars. The vehicles **104** may be fuel-powered vehicles (e.g., engines that consume fuel are used to generate propulsive force by creating electric current to power motors or to rotate axles and wheels), electric-powered vehicles (e.g., onboard or off board sources of electric current are used to power motors to generate propulsive force), and/or hybrid powered vehicles (e.g., vehicles that are powered by fuel-consuming engines and other sources of electric current). The vehicles **106** (e.g., vehicles **106**A-I) represent non-propulsion-generating vehicles, such as rail cars or other units that are propelled along the route **102** by the propulsion-generating vehicles **104**.

The term "vehicle" as used herein can be defined as a mobile machine that transports at least one of a person, people, or a cargo. For instance, a vehicle can be, but is not limited to being, a rail car, an intermodal container, a locomotive, a marine vessel, mining equipment, construction equipment, an automobile, and the like. A "vehicle system" includes two or more vehicles that are interconnected with each other to travel along a route. For example, a vehicle system can include two or more vehicles that are directly connected to each other (e.g., by a coupler) or that are indirectly connected with each other (e.g., by one or more other vehicles and couplers). A vehicle system can be referred to as a consist, such as a rail vehicle consist.

"Software" or "computer program" as used herein includes, but is not limited to, one or more computer readable and/or executable instructions that cause a computer or other electronic device to perform functions, actions, and/or behave in a desired manner. The instructions may be embodied in various forms such as routines, algorithms, modules or programs including separate applications or code from dynamically linked libraries. Software may also be implemented in various forms such as a stand-alone program, a function call, a servlet, an applet, an application, instructions stored in a memory, part of an operating system or other type of executable instructions. "Computer" or "processing element" or "computer device" as used herein includes, but is not limited to, any programmed or programmable electronic device that can store, retrieve, and process data. "Non-transitory computer-readable media" include, but are not limited to, a CD-ROM, a removable flash memory card, a hard disk drive, a magnetic tape, and a floppy disk. "Computer memory", as used herein, refers to a storage device configured to store digital data or information which can be retrieved by a computer or processing element. "Controller," "unit," and/or "module," as used herein, can to the logic circuitry and/or processing elements and associated software or program involved in controlling an energy storage system. The terms "signal", "data", and "information" may be used interchangeably herein and may refer to digital or analog forms.

At least one technical effect described herein includes generating command profiles and change indices for a trip of a vehicle system. The command profiles can dictate operational settings (e.g., throttle notch settings or other settings) of propulsion-generating vehicles in the vehicle system, and the change indices can dictate where and/or when assignments of the vehicles among different groups and/or fence positions in the vehicle system are to be changed. The command profiles and/or change indices may be generated before the vehicle system embarks on the trip, generated while the vehicle system is moving along a route during the trip, subsequent to completing the trip (e.g., to allow for comparison with how the operator controlled the vehicle system during the previous trip), or a combination thereof. The command profiles and/or change indices may be used to control which propulsion-generating vehicles in the vehicle system have the same or different operational settings (e.g., throttle notch settings) at different locations in the trip in order to control bunching of the vehicle system.

The propulsion-generating vehicles **104** may be arranged in consists **110**, **112**, **114**, as shown in FIG. **1**. Each consist **110**, **112**, **114** may include the propulsion-generating vehicles **104** directly connected with each other in the vehicle system **100**. While each consist **110**, **112**, **114** is shown as including multiple propulsion-generating vehicles **104**, one or more of the consists **110**, **112**, **114** may optionally include a single propulsion-generating vehicle **104**.

While the vehicle system **100** is shown in FIG. **1** as a train, alternatively, the vehicle system **100** may represent another vehicle system formed of vehicles other than locomotives (e.g., the propulsion-generating vehicles **104**) and railcars (e.g., the non-propulsion generating vehicles **106**). For example, the vehicle system **100** may represent several automobiles, trucks, marine vessels, off-highway vehicles other than rail vehicles, aerial vehicles (e.g., airplanes, drones, etc.), robots, or the like, joined together to travel along the route **102**.

In one embodiment, tractive efforts (e.g., power output, horsepower, speed, and the like) and/or braking efforts of the vehicle system **100** may be controlled to drive the vehicle system **100** along the route **102** from an origin location to a destination location. The tractive and/or braking efforts may be automatically controlled such that the tractive and/or braking efforts provided by the vehicles **104**, **106** without operator intervention involved in changing these efforts. Alternatively or additionally, the vehicle system **100** may provide prompts and notices to an operator that direct the operator how to manually control the efforts of the vehicle system **100**. For example, the system **100** may provide prompts to an operator to instruct the operator of which operational settings to use at a current time and/or which settings to use at upcoming times when the system **100** arrives at one or more upcoming locations. The operational settings (e.g., settings that control tractive effort, braking effort, etc.) of the propulsion-generating vehicles and/or non-propulsion-generating vehicles may be referred to herein as operational parameters.

The tractive efforts and braking efforts may be controlled by designating operational settings of the vehicle system **100** at one or more locations along the route **102**. By way of example, these operational settings can include power settings (e.g., throttle notch settings) that control the power output from the propulsion-generating vehicles **104** and brake settings (e.g., dynamic brake settings) that control the braking efforts of the propulsion-generating vehicles **104** and/or the non-propulsion generating vehicles **106**. The operational settings that are designated for a trip of the vehicle system **100** from a first location to a different, second location along the route **102** may be referred to as a trip plan. The designated operational settings can be expressed as a function of time elapsed during a trip along the route **102** and/or distance along the route **102** in the trip plan.

The designated operational settings can be computed in order to improve handling (e.g., control) of the vehicle system **100**. For example, the designated operational settings can be determined in order to reduce the frequency at which throttle notch settings and/or brake settings are changed, to reduce abrupt jerking movements of the vehicle system **100** or segments of the vehicle system **100**, to reduce forces exerted on the couplers **108**, and the like.

In one embodiment, different propulsion-generating vehicles **104** may have different operational settings at the same location and/or time along the route **102**. For example, the propulsion-generating vehicles **104** may be asynchronously controlled so that not all of the vehicles **104** in the vehicle system **100** and/or in a single consist **110**, **112**, **114** are controlled according to the same throttle and/or brake settings. Alternatively, the propulsion-generating vehicles **104** may be assigned into different groups (e.g., the consists **110**, **112**, **114** or other groups) with virtual "fences" between the groups. A fence can demarcate a pair of groups of the propulsion-generating vehicles **104** on opposite sides of the fence. For example, if a fence is established between the consists **112** and **114**, then the propulsion-generating vehicles **104**C-E in the consist **112** may operate using a first designated throttle notch setting while the propulsion-generating vehicles **104**F-G in the consist **114** may operate using a different, second designated throttle notch setting at the same time. Operation of the vehicle system **100** that involves two or more of the propulsion-generating vehicles

104 using different operational settings at the same time may be referred to as asynchronous distributed power operation in one embodiment.

FIGS. **2** through **4** illustrate embodiments of how operations of the propulsion-generating vehicles **104** in the vehicle system **100** can be controlled in order to improve handling of the vehicle system **100** during a trip while achieving one or more trip objectives and while remaining within operating constraints on the trip. A trip objective can be a goal that the vehicle system **100** attempts to achieve by operating according to operational settings designated for the vehicle system **100**. The trip objectives may include a reduction in fuel consumption, emission generation, and/or travel time relative to traveling with the same vehicle system **100** along the same route **102**, but using different operational settings at one or more locations along the route **102**. Another example of a trip objective can include fuel balancing, where the operational settings are determined in order to keep or maintain the amount of fuel stored onboard the different propulsion-generating vehicles to be the same or within a designated amount (e.g., 1%, 3%, 5%, 10%, or another value) over an entirety of the trip, over one or more segments of the trip, or the like. For example, different propulsion-generating vehicles may consume fuel at different rates and/or may have different amounts of fuel onboard prior to departure for a trip. The operational settings for the trip can be determined so that the different propulsion-generating vehicles carry the same or similar amounts of fuel. The operational settings can cause vehicles carrying more fuel to consume more fuel than those vehicles carrying less fuel in order to keep the distribution of fuel even across the vehicle system **100**. For example, the vehicles carrying less fuel than other vehicles may be restricted to a smaller range of throttle notch settings than vehicles carrying more fuel. This can prevent the vehicles carrying less fuel from consuming more fuel than the vehicles carrying more fuel. Over time, the notch restrictions on the vehicles carrying less fuel can cause the balance of fuel carried by the vehicles in the vehicle system to become more even (e.g., the amount of fuel carried by the vehicles is within a designated amount or range of each other).

Another example of a trip objective can be a number of nodes in the vehicle system **100**. A node can represent a vehicle or coupler in the vehicle system **100** that is disposed between a coupler in tension and a coupler in compression. For example, if the coupler **108** between the vehicles **104**E and **106**D is in compression while the coupler **108** between the vehicles **104**C and **104**D is in tension, then the coupler **108** between the vehicles **104**D and **104**E may represent a node of the vehicle system **100**. A trip objective can be a reduction or elimination of nodes in the vehicle system **100** for an entire trip or one or more segments of the trip, or keeping the number of nodes in the vehicle system below a designated number. For example, if the number of nodes in the vehicle system **100** can be reduced by changing operational settings and/or fence positions at one or more locations along a trip, then the operational settings and/or fence positions can be changed to reduce the number of nodes.

The operating constraints may include speed limits (both lower limits on speed and upper limits on speed), power requirements (e.g., minimum requirements for power to propel the vehicle system **100** up an incline), time limitations on how long an operator may be working on the vehicle system **100**, a system-wide schedule for the travel of multiple vehicle systems on or across the route **102**, or the like. Other examples of operating constraints can include fuel consumption limits, where certain operational settings are not permitted for one or more propulsion-generating vehicles as these settings could cause the vehicles to consume more fuel or to consume fuel at a greater rate than desired. For example, a propulsion-generating vehicle may not be permitted to be assigned a notch setting that would cause the vehicle to consume more fuel than the vehicle is carrying and/or consume fuel at such a rate that the vehicle will not have sufficient fuel to complete a trip.

Another operating constraint can include engine derating. One or more engines of the propulsion-generating vehicles may be derated and unable to generate the horsepower or tractive effort associated with the rating of the engines. The decreased output or capability of these engines may be used to limit what operational settings are assigned to different vehicles to prevent the vehicles from having to operate the engines at levels that exceed the derated capabilities of the engines. This deration may be due to an onboard failure or as the result of a desired limit (e.g., to maintain a desired train horsepower per ton).

Another example of an operating constraint can include a notch delta penalty. Such a penalty can restrict how much and/or how quickly an operational setting of a vehicle is allowed to change. For example, a notch delta penalty may not allow the throttle notch setting for a propulsion-generating vehicle to change by more than three positions (e.g., throttle notch one to throttle notch four). Instead, the vehicle may be limited to changing throttle positions by three positions or less at a time.

Another example of an operating constraint can be a limitation on how frequently the group assignment is changed. For example, such a constraint may not permit the group assignment of the vehicle system **100** to change more frequently than a designated frequency or time period.

FIG. **2** is a flowchart of one embodiment of a method **200** for operating the vehicle system **100** shown in FIG. **1**. The method **200** may be used in conjunction with the vehicle system **100**. For example, the method **200** may be used to create and/or modify a trip plan for the vehicle system **100** that designates operational settings to be used to asynchronously control the operations of the propulsion-generating vehicles **104** (shown in FIG. **1**) during a trip along the route **102** (shown in FIG. **1**) in order to improve handling of the vehicle system **100**. Additionally or alternatively, the method **200** may be used to autonomously control the operations of the propulsion-generating vehicles **104** in an asynchronous manner during a trip along the route **102** in order to improve handling of the vehicle system **100**. Additionally or alternatively, the method **200** may be used to direct an operator to manually control the operations of the propulsion-generating vehicles **104** in an asynchronous manner during a trip along the route **102** in order to improve handling of the vehicle system **100**.

At **202**, a synchronous trip plan for the trip is obtained. The trip plan may be synchronous in that the operational settings of the propulsion-generating vehicles **104** that are designated by the trip plan may be the same for the propulsion-generating vehicles **104** at the same locations. The trip plan may designate the operational settings of the vehicle system **100** in order to reduce fuel consumed, emissions generated, and the like, by the vehicle system **100** relative to the vehicle system **100** traveling along the route **102** in the trip using one or more different operational settings (e.g., according to manual control and/or another, different trip plan). One or more examples of trip plans (also referred to as mission plans or trip profiles) and how the trip plans are determined are provided in U.S. patent application Ser. No.

11/385,354 (referred to herein as the "'354 Application"), the entire disclosure of which is incorporated by reference.

In one embodiment, the synchronous trip plan can be created at **202** by collecting and using trip data, route data, and vehicle data. The trip data includes information representative of one or more constraints of the trip, such as a starting location, an ending location, one or more intermediate locations between the starting and ending locations, a scheduled time of arrival at one or more locations, weather conditions (e.g., direction and speed of wind) and the like. The route data includes information representative of the route **102**, including grades, curvatures, speed limits, and the like. The vehicle data includes information representative of capabilities and/or limitations of the vehicle system **100**, such as power outputs that can be provided by the vehicle system **100**, tractive efforts provided by the propulsion-generating vehicles **104** at different throttle notch settings, braking efforts provided by the vehicles **104**, **106** at different brake notch settings, and the like. The vehicle data also can include the size (e.g., mass, length, number of axles, weight distribution, or the like) of the vehicles **104** and/or **106** in the vehicle system **100**. The trip plan can be computed from the beginning to the end of the trip and can designate speeds of the vehicle system **100**, synchronous notch settings of the propulsion-generating vehicles **104**, and synchronous brake settings of the propulsion-generating vehicles **104**, **106** at locations along the route **102**.

At **204**, parameters are determined at one or more different locations along the route **102**. The parameters may be determined prior to the vehicle system **100** embarking on the trip and/or during travel of the vehicle system **100** in the trip and prior to arriving at the one or more different locations. The parameters can be referred to as movement parameters, and can include estimates or measurements of one or more aspects of the vehicle system **100** and/or the route **102**. Several examples of parameters are described below. The parameters can be representative of forces exerted on the couplers, energies stored in the couplers, relative velocities of neighboring vehicles of the vehicles in the vehicle system, natural forces exerted on one or more segments of the vehicle system between two or more of the propulsion-generating vehicles, distances between neighboring vehicles in the vehicle system, momentum of one or more vehicles and/or one or more groups of the vehicles, virtual forces exerted on one or more of the vehicles, or the like. The momentum may include changes in momentum, momentum transport, or the like.

One example of these parameters is coupler parameters. Coupler parameters include one or combinations of estimates, calculations, measurements, and/or simulations of coupler forces and/or energies stored in the couplers **108** (shown in FIG. **1**) of the vehicle system **100** at one or more locations along the route **102** for the trip. In one embodiment, the coupler forces and/or energies stored in the couplers **108** can be estimated from a model of the couplers **108**. For example, the couplers **108** between the vehicles **104**, **106** can be modeled as springs having spring constants k and a damper (e.g., the mass of the vehicles **104** and/or **106** to which the modeled spring is coupled). Due to the tractive efforts (e.g., power outputs) provided by the propulsion-generating vehicles **104**, the states of the vehicle system **100** may undergo a transition and the forces exerted on the couplers **108** and/or the energies stored in the couplers **108** that result from this transition at different locations along the route **102** can be calculated (e.g., estimated or simulated) as a function of the tractive efforts provided by the propulsion-generating vehicles **104** at the different locations.

By way of example only, a first coupler **108** may be expected to become compressed due to the expected deceleration of a first leading propulsion-generating vehicle **104** and the expected acceleration of a first trailing propulsion-generating vehicle **104** that are caused by changes in the grade of the route **102** during travel according to the synchronous trip plan (e.g., when traversing a valley or low point in the route **102**). Another, second coupler **108** may be expected to become stretched due to the expected acceleration of a second leading propulsion-generating vehicle **104** and the expected deceleration of a second trailing propulsion-generating vehicle **104** that are caused by changes in the grade of the route **102** during travel according to the synchronous trip plan (e.g., when traversing a peak or high point in the route **102**). The first coupler **108** may be estimated to have a greater compressive force than the second coupler **108** in this example.

One or more relationships between the coupler forces and/or energies stored in the couplers **108** can be used to determine the coupler parameters. One example of a coupler parameter includes:

$$P_c = \sum_{j=1}^{nc} f_j^2 \quad \text{(Equation \#1)}$$

where P_c represents a coupler parameter, nc represents a number of the couplers **108** in the vehicle system **100** (e.g., the total number of couplers **108**), and f represents the estimated or modeled coupler force. The coupler parameter (P_c) of Equation #1 may represent the sum of squares of all coupler forces between the first coupler **108** (e.g., when j=1) and the n^{th} coupler **108** in the vehicle system **100**. Another example of a coupler parameter includes the maximum coupler force of the couplers **108** at a location along the route **102**.

Another example of a coupler parameter includes:

$$E = \sum_{j=1}^{nc} 0.5 \frac{f_j^2}{k_j} \quad \text{(Equation \#2)}$$

where E represents another coupler parameter and k represents the spring constant of a modeled spring representative of the j^{th} coupler **108**. The coupler parameter (E) of Equation #2 may represent the total energy stored in the couplers **108** of j=1 through j=nc in the vehicle system **100** at a location along the route **102**. Additionally or alternatively, the coupler parameter may include or represent an average of an absolute value of the coupler forces in the vehicle system **100**. Additionally or alternatively, the coupler parameter may include or represent a sum, maximum, average, median, and the like of the absolute values of the coupler forces in the vehicle system **100** that are at least as large as a designated upper limit. The upper limit may be based on the location of the vehicle system **100** (e.g., the limit is based on the terrain being traveled over), vehicle data (e.g., the type of vehicles in the system **100**), coupler data (e.g., the type, health, age, and the like, of the couplers in the system **100**), and the like.

One or more of the coupler parameters described above and/or another coupler parameter that represents coupler force and/or energy stored in the couplers **108** may be determined for the vehicle system **100** at one or more locations along the route **102** during the trip. For example, prior to arriving at the locations, the coupler parameters may be calculated or estimated for those locations using the trip data, the vehicle data, and/or the route data.

FIG. **3** illustrates coupler parameters **310** (e.g., coupler parameters **310**A-J) that are estimated for a vehicle system **300** to travel along a route **302** in accordance with one example. The vehicle system **300** may represent the vehicle system **100** (shown in FIG. **1**) or a segment of the vehicle system **100**. The vehicle system **300** includes propulsion-generating vehicles **304** (e.g., vehicles **304**A-C), which can represent the propulsion-generating vehicles **104** (shown in FIG. **1**) and non-propulsion generating vehicles **306** (e.g., vehicles **306**A-G), which can represent the non-propulsion generating vehicles **106** (shown in FIG. **1**). The vehicles **304**, **306** are connected by couplers **108** (shown in FIG. **1**). The route **302** may represent a portion of the route **102** (shown in FIG. **1**).

The coupler parameters **310** are shown alongside a horizontal axis **312** that is representative of locations along the length of the vehicle system **300** and a vertical axis **314** that is representative of magnitudes of the coupler parameters **310**. The size of the coupler parameters **310** indicates the relative sizes of the coupler forces and/or stored energies represented by the parameters **310**. The coupler parameters **310** represent the coupler forces and/or energies of the couplers **108** joined to the respective vehicle **304**, **306**. For example, the coupler parameter **310**A represents the coupler forces and/or stored energies of the coupler **108** connected to the vehicle **304**A (or twice the coupler force and/or stored energy of the single coupler **108** connected to the vehicle **304**A), the coupler parameter **310**B represents the coupler forces and/or stored energies of the couplers **108** connected to the opposite ends of the vehicle **304**B, the coupler parameter **310**C represents the coupler forces and/or stored energies of the couplers **108** connected to the opposite ends of the vehicle **306**A, and so on. Negative coupler parameters **310** (e.g., the parameters **310**A-B and **310**G-J extending below the horizontal axis **312**) can represent couplers **108** undergoing compressive forces and positive coupler parameters **310** (e.g., the parameters **310**C-F extending above the horizontal axis **312**) can represent couplers **108** undergoing tensile forces.

The coupler parameters **310** can be estimated for travel over the route **302** prior to the vehicle system **300** actually traveling over the route **302** and using the synchronous trip plan established for travel over the route **302**. The coupler parameters **310** may be calculated using one or more of the relationships described above, or in another manner that represents compression and/or tension in the couplers **108**. In one embodiment, relatively large variances in the coupler parameters **310** can indicate poor handling of the vehicle system **300**. For example, a trip plan that causes a vehicle system **300** to have relatively large, positive coupler parameters **310** and large, negative coupler parameters **310** may indicate that traveling according to the trip plan will result in poor handling of the vehicle system **300** relative to a trip plan that results in smaller positive coupler parameters **310** and/or smaller negative coupler parameters **310**.

Returning to the discussion of the method **200** shown in FIG. **2**, another example of the parameters is terrain excitation parameters. Terrain excitation parameters represent grades of the route **102** (shown in FIG. **1**) at the different locations, masses of one or more of the vehicles **104**, **106** (shown in FIG. **1**) in the vehicle system **100** (shown in FIG. **1**) at the different locations, and/or tractive efforts that are to be provided by one or more of the propulsion-generating vehicles **104** at the different locations according to a trip plan (e.g., a synchronous trip plan).

A terrain index can represent the terrain under each vehicle **104**, **106** as the vehicle system **100** travels along the route **102**. The terrain index may have a static component (e.g., a DC or average or steady component) and a dynamic component (e.g., an AC or varying or oscillating component). The static component of the terrain index can be defined as:

$$\mu_i=-m_i g_i+T_i \quad \text{(Equation \#3)}$$

where u $_i$, represents the static component of the terrain index beneath the ith vehicle **104**, **106** in the vehicle system **100**, m_i represents the mass of the ith vehicle **104**, **106**, g_i represents the grade of the route **102** beneath the ith vehicle **104**, **106**, and T_i represents a designated tractive effort and/or braking effort to be provided by the ith vehicle **104**, **106** according to the trip plan (e.g., the synchronous trip plan). In one aspect, a distribution of weight or mass of the vehicles in the vehicle system may not be even. For example, the masses of the vehicles in one location or portion of the vehicle system may be larger than the masses of the vehicles in other locations or portions of the vehicle system. Alternatively, the masses of the vehicles may be even throughout the vehicle system, such as the masses of all vehicles **104**, **106** being equal or within a designated range of one another, such as within 1%, 3%, 5%, 10%, or the like.

The dynamic component of the terrain index can be defined as:

$$\tilde{\mu}_i = -m_i g_i + T_i - \sum_{j=1}^{N} \mu_i \quad \text{(Equation \#4)}$$

where $\tilde{\mu}_i$ represents the dynamic component of the terrain index and N represents the number of vehicles **104**, **106** for which the terrain index is determined. In one embodiment, the coupler parameters **310** shown in FIG. **3** can represent the dynamic component of the terrain index for the vehicle system **300** instead of the coupler parameters of the vehicle system **300**.

In one embodiment, the terrain excitation parameter may be based on the dynamic component of the terrain index. For example, the terrain excitation parameter may be a filtered dynamic component of the terrain index and represented by:

$$e(k) = \sum_{i=1}^{k} \tilde{\mu}_i a^{k-1} \quad \text{(Equation \#5)}$$

$$e(i) = \tilde{\mu}_i a^{k-1} \quad \text{(Equation \#6)}$$

where e(k) represents the terrain excitation parameter for the vehicle system **100** beneath the kth vehicle **104**, **106**, a represents a configurable or tunable constant referred to as a spatial decay rate of terrain input and having a value between 0 and 1, e(i) represents the terrain excitation parameter for the ith vehicle **104**, **106** in the vehicle system **100**, and m represents the number of vehicles **104**, **106** in the vehicle system **100**.

FIG. **4** illustrates terrain excitation parameters **410** that are estimated for the vehicle system **300** to travel along the route **302** in accordance with one example. The terrain excitation parameters **410** are shown alongside a horizontal axis **412** representative of locations along the length of the vehicle system **300** and a vertical axis **414** representative of magnitudes of the terrain excitation parameters **310**.

As shown in FIG. **4**, when the trip plan directs the propulsion-generating vehicles **304**A-C to use the same braking efforts during traversal of the peak or apex in the route **302**, the terrain excitation parameters **410** increase along the length of the vehicle system **300** and then decrease. For example, the terrain excitation parameters **410** corresponding to locations below the back end of the vehicle system **300** to beneath the non-propulsion generating vehicle **306**C increase to a maximum, and then decrease to a minimum beneath the propulsion-generating vehicle **306**B, before increasing again beneath the propulsion-generating vehicle **306**A.

The terrain excitation parameters **410** can be estimated for travel over the route **302** prior to the vehicle system **300** actually traveling over the route **302** and using the synchronous trip plan established for travel over the route **302**. The terrain excitation parameters **410** may be calculated using one or more of the relationships described above, or in another manner that represents compression and/or tension in the couplers **108**. In one embodiment, relatively large terrain excitation parameters **410** (e.g., large positive and/or large negative values) can indicate poor handling of the vehicle system **300**. For example, a trip plan that causes a vehicle system **300** to have relatively large maximum or minimum terrain excitation parameters **410** may indicate that traveling according to the trip plan will result in poor handling of the vehicle system **300** relative to a trip plan that results in smaller maximum or minimum terrain excitation parameters **410**.

Returning to the discussion of the method **200** shown in FIG. **2**, another example of the parameters is node parameters. Node parameters represent a number of the nodes in the vehicle system **100** (shown in FIG. **1**) and/or a rate of movement of the nodes in the vehicle system **100**. A node can represent a location in the vehicle system **100** where an absolute value of force that is estimated to be exerted on a coupler **108** is less than a designated threshold. In order to identify the presence and locations of nodes, a rigid rope model of the vehicle system **100** may be used. In such a model, the couplers **108** are treated as having no slack and the vehicle system **100** is treated as traveling according to the trip plan (e.g., the synchronous trip plan). Locations where the couplers **108** are estimated to have relatively large compressive forces or relatively large tensile forces due to the tractive and/or braking efforts designated by the trip plan and due to the grades in the route **102** (shown in FIG. **1**) are not identified as nodes. Other locations where the couplers **108** are estimated to have relatively small or no compressive or tensile forces are identified as nodes.

With respect to the example shown in FIG. **3**, the coupler parameter **310**G may represent the location of a node in the vehicle system **300**. The number of nodes (e.g., one in the example of FIG. **3**, but alternatively may be a larger number) can be a node parameter. Additionally or alternatively, the rate of movement of the nodes in the vehicle system can be a node parameter. For example, as the vehicle system moves up and down different grades of the route and/or using tractive and/or braking efforts designated by the synchronous trip plan, the locations of the nodes within the vehicle system may change (e.g., move to another coupler **108**). This movement can be estimated as a speed or rate of movement, such as in units of number of couplers per second, number of vehicles per second, and the like.

Returning to the discussion of the method **200** shown in FIG. **2**, another example of the parameters is neighboring velocity parameters. The neighboring velocity parameters can represent differences in speed between neighboring vehicles **104** and/or **106** in the vehicle system **100** shown in FIG. **1**. For example, speeds of the vehicles **104**, **106** traveling according to a synchronous trip plan can be estimated based on the sizes (e.g., masses) of the vehicles **104**, **106**, the location of the vehicles **104**, **106** in the vehicle system **100**, the grade of the route **102**, and the like. Because the couplers **108** between the vehicles **104**, **106** are not entirely rigid bodies, there may be some differences in the speeds of the vehicles **104**, **106** that are directly connected with each other.

For example, a leading propulsion-generating vehicle **104** that is accelerating according to a trip plan may at least temporarily travel faster than another, heavier propulsion-generating vehicle **104** that is directly coupled to the leading propulsion-generating vehicle **104** and/or than a non-propulsion generating vehicle **106** that is directly coupled to the leading propulsion-generating vehicle **104**. As another example, when cresting a hill, a first vehicle **104** or **106** that is on the downward sloping side of the hill may be temporarily traveling faster than a second vehicle **104** or **106** that is directly connected to the first vehicle **104** or **106** and that is on the upward sloping side of the hill. In another example, when traversing a dip or low point in the route **102**, a first vehicle **104** or **106** that is on the upward sloping side of the low point may be temporarily traveling slower than a second vehicle **104** or **106** that is directly connected to the first vehicle **104** or **106** and that is on the downward sloping side of the low point. The differences in speeds between the neighboring (e.g., adjacent) vehicles **104** and/or **106** can vary forces exerted on the couplers **108** to generate jerking movements that decrease the handling of the vehicle system **100**.

Node parameters are another example of the parameters that may be determined. Node parameters represent a number of the nodes in the vehicle system **100** (shown in FIG. **1**) and/or a rate of movement of the nodes in the vehicle system **100**. A node can represent a location in the vehicle system **100** where an absolute value of force that is estimated to be exerted on a coupler **108** is less than a designated threshold. In order to identify the presence and locations of nodes, a rigid rope model of the vehicle system **100** may be used. In such a model, the couplers **108** are treated as having no slack and the vehicle system **100** is treated as traveling according to the trip plan (e.g., the synchronous trip plan). Locations where the couplers **108** are estimated to have relatively large compressive forces or relatively large tensile forces due to the tractive and/or braking efforts designated by the trip plan and due to the grades in the route **102** (shown in FIG. **1**) are not identified as nodes. Other locations where the couplers **108** are estimated to have relatively small or no compressive or tensile forces are identified as nodes.

Another example of the parameters is momentum. The momentum can be the momentum of the vehicle system, one or more vehicles in the vehicle system, and/or one or more groups of vehicles in the vehicle system. Differences in momentum between different vehicles or groups of vehicles in the vehicle system can indicate reduced parameters and/or increased forces on couplers. For example, a larger momentum for a group of vehicles that includes the vehicles **104**A-E and **106**A-C and a smaller momentum for a group of vehicles that includes the vehicles **104**F-G and **106**D-I can indicate that the coupler **108** or couplers **108** between these vehicle groups may be experiencing relatively large forces (e.g., tensile forces) that result in reduced parameters of the vehicle system (e.g., relative to smaller momenta and/or smaller differences in momenta between the vehicle groups).

Another example of the parameters is fuel usage. This parameter indicates how much fuel is consumed or planned to be consumed during one or more upcoming segments of the trip (or over the entire trip). The fuel usage can be calculated by examining the throttle settings, different amounts of electric current received from another location or other vehicles (as described below), grades of the route, curvatures of the route, speed limits of the route, weights of the vehicles, number of vehicles in a vehicle system, makes or models of the vehicles, and other factors that contribute to fuel being consumed. In one embodiment, different designated amounts of fuel usage may be associated with different throttle settings, different amounts of electric current received from another location or other vehicles, different grades of the route, different curvatures of the route, different speed limits of the route, different weights of the vehicles, different numbers of vehicles in a vehicle system, different makes or models of the vehicles, and/or different combinations of these factors may be associated with different estimated or previously measured amounts of fuel that will be consumed. The estimated fuel usage can then be determined by determining which combination of these factors matches or more closely matches (relative to other combinations) the factors applicable to a vehicle system for which the trip plan is being created.

Another example of the parameters is wear and tear, or remaining lifespan. This parameter indicates how much damage is imparted on or how much useful life is lost by the vehicle system traveling in the trip. In one embodiment, previous trips of other vehicle systems may be associated with different amounts of wear and tear, or reduced lifespans, of the vehicle systems. The estimated wear and tear, or reduced lifespan, can then be determined for an upcoming trip of a vehicle system by determining which previous trip matches or more closely matches (relative to other trips) the upcoming trip of a vehicle system.

Another example of the parameters is passenger discomfort. This parameter indicates how physically uncomfortable the trip is for one or more passengers onboard the vehicle system. The passenger discomfort can be calculated determined based on operational characteristics of the trip, such as how many times a throttle is changed, how many times a brake is applied, how many curves the vehicle system travels over, how many undulations the vehicle system travels over, etc. In one embodiment, different designated amounts of passenger discomfort (e.g., expressed numerically, such as along a scale of zero to ten or another range) may be associated with different numbers of times that a throttle is changed, different numbers of times a brake is applied, different numbers of curves that the vehicle system will travel over, different numbers of undulations that the vehicle system will travel over, and/or different combinations of these factors may be associated with different designated amount of passenger discomfort. The estimated passenger discomfort for an upcoming trip can then be determined by determining which combination of these factors matches or more closely matches (relative to other combinations) the factors applicable to a vehicle system for which the trip plan is being created.

Another example of the parameters is time of arrival. This parameter indicates when the vehicle system will arrive at one or more locations, such as a final destination, of a trip. The time of arrival can be estimated based on a distance to a location, speed limits of the route, and/or upper limits on how fast the vehicle system is able to move. Based on how far the vehicle system has to travel, how fast the vehicle system is allowed to travel, and/or how fast the vehicle system is able to travel, the estimated time to travel to a location can be calculated and the estimated time of arrival can be determined. Reducing this parameter can involve having an earlier time of arrival.

In one embodiment, the parameters may not be determined based on a synchronous trip plan. A synchronous trip plan may not be obtained at **202**, but the parameters can be determined (e.g., estimated, calculated, or the like) based on one or more of the trip data, route data, and/or vehicle data. For example, without having a previously generated trip plan for an upcoming or current trip, one or more of the parameters described herein may be determined using grades of the route, curvatures of the route, speed limits of the route, weight of the vehicle system, or the like.

At **206**, total power outputs that are to be provided by the vehicle system **100** are determined at the locations along the route **102**. For example, the total power outputs that are to be provided, in the aggregate, by the propulsion-generating vehicles **104** in the vehicle system **100** may be determined for at least some, or all, the same locations at which the parameters are determined at **204**.

In one embodiment, the total power outputs can be determined from the synchronous trip plan. For example, the synchronous trip plan may designate the total power outputs to be provided by the propulsion-generating vehicles **104** at the locations. Alternatively, the synchronous trip plan can designate the individual power outputs to be provided by each of the propulsion-generating vehicles **104** at the locations, and the total power outputs of the vehicle system **100** can be determined from the sum or other aggregate of these individual power outputs. In another embodiment, the total power outputs can be derived from other designated operational settings of the synchronous trip plan at the locations. For example, the total power outputs may be calculated from the designated speeds, accelerations, or other settings of the synchronous trip plan at the locations. The total power outputs may be determined before, during, or after the parameters are determined. Optionally, the total power output can be determined without a trip plan or synchronous trip plan. For example, based on the mass of the vehicle system, the locations of the propulsion-generating vehicles in the vehicle system, and the grades of the route, an estimate or calculation of the total power needed to propel the vehicle system along the route (e.g., to achieve the trip objective subject to operating constraints) may be made. Alternatively, an operator of the vehicle system **100** can designate or input the total power output. The operator can provide the total power output so that the method **600** can determine the operational settings that result in providing the total power output provided by the operator.

At **208**, asynchronous operational settings for the vehicle system **100** are determined. For example, the total power outputs can be divided among the propulsion-generating vehicles **104** in the vehicle system **100** at the locations and based on the parameters by determining different operational settings for different vehicles **104**, **106** at these locations. The total power outputs of the synchronous trip plan may be divided among the propulsion-generating vehicles **104** by designating the same throttle and/or brake settings for each of the propulsion-generating vehicles **104**. Using the parameters that are determined at the locations along the route **102**, the same total power outputs at these locations can be divided among the propulsion-generating vehicles **104** by designating different throttle and/or brake settings for the propulsion-generating vehicles **104**. For example, the synchronous trip plan may direct the seven propulsion-generating vehicles **104** to use the same throttle setting to generate a total power output of 15,000 horsepower at a location along the route **102**. Optionally, the total power output may be determined without the aid of the synchronous trip plan, but may be determined using vehicle data, trip data, and/or route data. The 15,000 horsepower output may be asynchronously divided among the propulsion-generating vehicles **104** by assigning different throttle and/or brake settings to the different propulsion-generating vehicles **104**. The propulsion-generating vehicles **104** may use the different operational settings in order to provide at least the 15,000 horsepower, but with improved handling of the vehicle system **100** relative to the synchronous trip plan and/or relative to using other operational settings.

In one embodiment, the asynchronous operational settings are determined based on the parameters for all of the locations along the route **102** for which the parameters were estimated. Alternatively, the asynchronous operational settings may be determined for a subset of these locations, such as for the locations associated with parameters that exceed one or more designated thresholds. The parameters that exceed the thresholds may indicate locations or segments of the route **102** where handling of the vehicle system **100** may be more difficult than other locations or segments of the route **102**.

The different operational settings of the propulsion-generating vehicles **104** may be designated for use by the vehicles **104** prior to embarking on the trip. For example, before the vehicle system **100** begins the trip (e.g., leaves a location of trip origin), the method **200** may be used to convert the same operational settings designated by the synchronous trip plan into the different (e.g., asynchronous) operational settings at one or more locations along the route **102**. Then, when the vehicle system **100** arrives at or approaches the locations, the asynchronous operational settings may be used to control the propulsion-generating vehicles **104** (e.g., autonomously or by directing an operator to manually implement the asynchronous operational settings).

Alternatively, the method **200** may be used to convert the operational settings of the synchronous trip plan into the asynchronous operational settings in real time. By "real time," it is meant that, in one embodiment, the operational settings of the synchronous trip plan that are associated with one or more locations along the route **102** (e.g., for implementation by the propulsion-generating vehicles **104** at those locations) can be converted into the asynchronous operational settings after the vehicle system **100** has begun traveling on the route **102** for the trip, but before or just as the vehicle system **100** arrives at the one or more locations. The vehicle system **100** may convert the operational settings on an as-needed basis, such as by converting the operational settings of the synchronous trip plan for a closer first location, and then converting the operational settings of the synchronous trip plan for a farther second location after passing the first location.

With respect to using the parameters to convert the operational settings of the synchronous trip plan into asynchronous operational settings, the method **200** may include (e.g., at **208**) determining different operational settings for at least two or more of the propulsion-generating vehicles **104** at a location along the route **102** in order to change one or more of the parameters, such as to one or more designated values or limits. For example, the method **200** may include attempting to reduce or minimize one or more of the parameters by changing the operational settings from the synchronous trip plan. By "minimize," it is meant that the value of one or more of the parameters is reduced relative to the parameters as determined (e.g., estimated or simulated) from the synchronous trip plan, but not necessarily reduced to the absolute lowest value possible. "Minimizing" also can mean reducing the value to at least a designated limit, but not necessarily the smallest possible value. By way of example only, minimizing the parameters can include reducing one or more coupler parameters, terrain excitation parameters, node parameters, and/or neighboring velocity parameters relative to the corresponding coupler parameters, terrain excitation parameters, node parameters, and/or neighboring velocity parameters that are estimated using the synchronous trip plan, but not necessarily to a value of zero.

The designated limits to which the parameters are changed may be based on vehicle data and/or route data. For example, the limits may be expressed as a function of the terrain over which the vehicle system travels. As a result, the limits can be different at different locations along the route. As another example, the limits may be expressed as a function of the vehicle size (e.g., weight, weight distribution, length, and the like), the type of vehicle (e.g., the power output capability of the system or vehicle **104**), the type of coupler (e.g., the strength, age, and/or health of the couplers), and the like. Optionally, the designated limits may change value, such as to account for hysteresis or other impacts on the values of the parameters over time.

The parameters that are estimated or simulated using the synchronous operational settings may be referred to as synchronous parameters and the parameters that are estimated or simulated using asynchronous operational settings may be referred to as asynchronous parameters. The parameters can be reduced by estimating or simulating the synchronous parameters, changing the synchronous operational settings to asynchronous operational settings (while keeping the total power output of the vehicle system **100** at least as large as the total power output that would be obtained using the synchronous operational settings), estimating or simulating the asynchronous parameters, and comparing the synchronous parameters with the asynchronous parameters. Several iterations of this process may be performed so that several potential asynchronous parameters and associated asynchronous operational settings are determined. Then, the asynchronous operational settings associated with one or more asynchronous parameters that are reduced relative to the synchronous parameters may be selected for use at the associated location along the route **102**. Additionally or alternatively, a history of parameters using synchronous and/or asynchronous operational settings and parameters (e.g., as measured and/or estimated) from previous trips of the vehicle system **100** along the route **102** may be used to determine the asynchronous operational settings associated with reduced parameters.

In one embodiment, the asynchronous operational settings are directly determined without using a synchronous trip plan (e.g., without using the synchronous operational settings or by basing the asynchronous operational settings on previously generated synchronous operational settings). For example, instead of first obtaining or determining a synchronous trip plan and then determining the asynchronous operational settings from the synchronous trip plan, the asynchronous operational settings may be determined directly from data such as vehicle data and/or route data. In one example, the asynchronous operational settings may be determined by determining one or more solutions to an optimization problem represented by (and referred to as Equation #7):

$$\min_{u_1(x), \ldots, u_n(x)} \alpha(x) \times f(u_1, \ldots, u_n) + \beta(x) \times \text{fuel}(u_1, \ldots, u_n) + \gamma(x) \sum_{i=1}^{n} (u_i - u_{is})^2$$

where $u_i(x), \ldots, u_n(x)$ represent tractive efforts (e.g., power outputs) of the propulsion-generating vehicles **104** numbered 1 through n in the vehicle system **100** that are to be determined by changing the synchronous operational settings (where n represents the number of vehicles **104** having operational settings that are to be modified). For example, $u_i(x), \ldots, u_n(x)$ may represent the variables in the above Equation #7 that are to be solved for and used to determine the asynchronous operational settings. The variable $u_i(x)$ represents the tractive effort provided by the i^{th} propulsion-generating vehicle **104** in the vehicle system **100** at the location (x) using asynchronous operational settings while the variable $u_{is}(x)$ represents the tractive effort provided by the i^{th} propulsion-generating vehicle **104** in the vehicle system **100** at the location (x) using synchronous operational settings. When the tractive efforts $u_i(x), \ldots, u_n(x)$ are determined, then the operational settings that are associated with the tractive efforts $u_i(x), \ldots, u_n(x)$ may be determined (e.g., by identifying which throttle and/or brake settings provides the associated efforts $u_i(x), \ldots, u_n(x)$). Optionally, the variables $u_i(x), \ldots, u_n(x)$ can include or represent the braking efforts provided by the vehicles **104** and/or **106** of the vehicle system **100**. The variable x represents a location or distance along the route **102**, and may change for different locations for which the tractive efforts $u_i(x), \ldots, u_n(x)$ are being determined.

The function $f(\,)$ can represent a function that captures (e.g., mathematically represents) handling of the vehicle system **100**, and is referred to as a vehicle handling function. While the vehicle handling function is shown in Equation #7 as being dependent on the tractive efforts $u_i(x), \ldots, u_n(x)$ of the propulsion-generating vehicles **104**, the vehicle handling function may additionally or alternatively be dependent on one or more other factors, such as terrain (e.g., grade and/or curvature of the route **102**), a make-up of the vehicle system **100** (e.g., the distribution of weight, propulsion-generating vehicles **104**, and/or non-propulsion generating vehicles **106** in the vehicle system **100**), and/or speeds of the vehicle system **100** using the synchronous operational settings.

The function fuel( ) can represent a function that captures (e.g., mathematically represents) how much fuel is consumed by the vehicle system **100** (e.g., by the propulsion-generating vehicles **104**) when the tractive efforts $u_i(x), \ldots, u_n(x)$ are generated by the propulsion-generating vehicles **104** at the respective locations (x) along the route **102**.

The variables α, β, and γ in Equation #7 can represent tuning parameters that may be manually or autonomously changed in order to control the relative weights of different terms in the equation. The variable α(x) can represent a tuning parameter that is based on the total variation or other variation in the grade of the route **102** beneath the vehicle system **100** at a location (x) along the route **102**. For example, the variable α(x) can represent roughness of the route **102**, which can be defined as:

$$\alpha(x) = \sum_{i=1}^{n-1} |g_i - g_{i+1}| \quad \text{(Equation \#8)}$$

where g_i represents the grade of the route **102** underneath the i^{th} vehicle **104** or **106** at the location or distance (x). Optionally, the grade can be scaled by mass of the vehicles **104**, **106** in the above Equation #8. In one embodiment, one or more of the variables α, β, and γ may be based on vehicle data and/or route data. For example, α, β, and/or γ may be expressed as a function of the type of vehicles in the vehicle system, the age and/or health of the vehicles, the tractive and/or braking output capabilities of the vehicles, the size of the vehicle system, and the like. As another example, α, β, and/or γ may be expressed as a function of the location of the vehicle system and/or the terrain over which the vehicle system is currently located. As another example, α, β, and/or γ may be expressed as a function of the type, age, and/or health of couplers in the vehicle system.

The variables α, β, and γ may have values that change in order to alter the relative importance (e.g., weight) in the equation on handling of the vehicle system **100**, fuel consumption of the vehicle system **100**, and how far or close the asynchronous operational settings should remain to the synchronous operational settings (e.g., the degree of change in the operational settings that is allowed to occur). In one example, the values of the variables α, β, and γ may be α(x)=1, β(x)=0, and γ(x)=0, which can result in only the handling performance of the vehicle system **100** being improved, while the impact of changing the operational settings on fuel consumption and the difference between the synchronous and asynchronous operational settings are essentially ignored.

The values of the variables α, β, and γ may change based on distance (x) along the route **102**. For example, if α(x) is represented by Equation #8, then the values of β(x) and γ(x) to be nonzero constants can cause more emphasis to be placed on the vehicle handling function in Equation #7 in locations where the terrain beneath the route **102** is relatively more difficult (e.g., variations in the grade are more severe and/or more frequent).

As described above, different values of tractive efforts $u_i(x), \ldots, u_n(x)$ may be inserted into Equation #7 in order to identify tractive efforts $u_i(x), \ldots, u_n(x)$ (e.g., and associated asynchronous operational settings) that reduce one or more of the parameters relative to the synchronous operational settings at one or more locations (x) along the route **102**. In one embodiment, the potential values of the tractive efforts $u_i(x), \ldots, u_n(x)$ may be limited based on constraints, such as upper and lower magnitude limits and rate bounds (e.g., limitations on how quickly the tractive efforts can change with respect to distance).

Also as described above, because the variable $u_i(x)$ represents the tractive effort provided by the i^{th} propulsion-generating vehicle **104** in the vehicle system **100** at the location (x) using asynchronous operational settings and the variable $u_{is}(x)$ represents the tractive effort provided by the i^{th} propulsion-generating vehicle **104** in the vehicle system **100** at the location (x) using synchronous operational settings, then a constraint that may applied to Equation #7 may be that the values of $u_i(x)$ may need to satisfy the following so that the total effort or total power output of the vehicle system **100** is not decreased by changing from the synchronous operational settings associated with $u_{is}(x)$ to the asynchronous operational settings associated with $u_i(x)$:

$$\sum_{i=1}^{n} u_i(x) = \sum_{i=1}^{n} u_{is}(x) \quad \text{(Equation \#9)}$$

The vehicle handling function ƒ( ) can be determined by attempting to reduce or minimize one or more of the parameters using different asynchronous operational settings (that result in different tractive efforts $u_i(x), \ldots, u_n(x)$being provided by the propulsion-generating vehicles **104**) at one or more locations along the route **102**. With respect to the coupler parameters, one or more functions representative of coupler forces or energy stored in the couplers **108** may be used to reduce or minimize the coupler parameters. These functions may be applied to the couplers **108** over the entire vehicle system **100**, within a segment of the vehicle system **100**, and/or between the first leading propulsion-generating vehicle **104**A and the last trailing propulsion-generating vehicle **104**G. By way of example only, these functions may include a sum of squares of the forces that are estimated to be exerted on the couplers **108**, the maximum value of the forces exerted on the couplers **108** and/or energies stored in the couplers **108**, the minimum value of the forces exerted on the couplers **108** and/or energies stored in the couplers **108**, the maximum absolute value of the forces exerted on the couplers **108** and/or energies stored in the couplers **108**, the sum of the forces exerted on the couplers **108** and/or energies stored in the couplers **108**, the absolute sum of the forces exerted on the couplers **108** and/or energies stored in the couplers **108**, and the like. Equations 1 and 2 above represent a couple of examples of such functions.

With respect to the terrain excitation parameters, one or more functions representative of the terrain excitation parameters may be used to reduce or minimize the terrain excitation parameters. For example, different combinations of tractive efforts $u_i(x), \ldots, u_n(x)$ may be used in attempts to determine which combination results in a function of the terrain excitation parameters being reduced or minimized. One example of such a function includes:

$$f(\mu) = \sum_{k=1}^{N} e(k)^2 \quad \text{(Equation \#10)}$$

where $e(k)^2$ represents the square of the terrain excitation parameter for the k^{th} vehicle **104**, **106** in the vehicle system **100** including N vehicles **104**, **106**. The sum of the squares may be determined for the entire vehicle system **100**, within a segment of the vehicle system **100**, and/or between the first leading propulsion-generating vehicle **104**A and the last trailing propulsion-generating vehicle **104**G.

Another example of a function of the terrain excitation parameters includes:

$$f(\mu) = k\left|\overset{max}{e(k)}\right| \quad \text{(Equation \#11)}$$

Such a function determines the maximum terrain excitation parameter and may be used to identify the largest terrain excitation parameter in the entire vehicle system **100**, within a segment of the vehicle system **100**, and/or between the first leading propulsion-generating vehicle **104**A and the last trailing propulsion-generating vehicle **104**G.

Another example of a function of the terrain excitation parameters includes:

$$f(\mu) = \Sigma|e(k)| \quad \text{(Equation \#12)}$$

Such a function determines the sum of the terrain excitation parameters and may be used to identify the sum of the terrain excitation parameters in the entire vehicle system **100**, within a segment of the vehicle system **100**, and/or between the first leading propulsion-generating vehicle **104**A and the last trailing propulsion-generating vehicle **104**G.

With respect to the node parameters, different combinations of tractive efforts $u_i(x), \ldots, u_n(x)$ may be used in attempts to determine which combination results in the number of nodes being reduced or minimized and/or which combination results in the rate of movement of one or more nodes being reduced or minimized.

With respect to the neighboring velocity parameters, one or more functions representative of the neighboring velocity parameters may be used to reduce or minimize the neighboring velocity parameters. For example, different combinations of tractive efforts $u_i(x), \ldots, u_n(x)$ may be used in attempts to determine which combination results in a function of the neighboring velocity parameters being reduced or minimized. One example of such a function includes:

$$f(v) = \sum_{i=1}^{N-1} (v_i - v_{i+1})^2 \quad \text{(Equation \#13)}$$

where v_i represents the velocity of the i^{th} vehicle **104** or **106** in the vehicle system **100** having N vehicles **104**, **106** and the term $(v_i - v_{i+1})$ represents the difference in velocities of neighboring vehicles **104** and/or **106**.

Another example of a function of the neighboring velocity parameters includes:

$$f(v) = \left|v_i \overset{max}{-} v_{i+1}\right| \quad \text{(Equation \#14)}$$

Such a function determines the maximum difference in velocities of the neighboring vehicles **104** and/or **106** and may be used to identify the neighboring velocity parameter in the entire vehicle system **100**, within a segment of the vehicle system **100**, and/or between the first leading propulsion-generating vehicle **104**A and the last trailing propulsion-generating vehicle **104**G.

With respect to momentum being used as a parameter, the tractive efforts and/or braking efforts (e.g., operational settings) may be determined for one or more locations along the route **102** in order to cause the vehicle system **100** and/or one or more vehicles **104**, **106** to slow down (relative to a current or previous speed) so that the momentum of the vehicle system **100** and/or one or more groups of vehicles **104**, **106** to decrease (relative to a current or previous momentum). For example, the operational settings may be determined to cause the momentum of one group of the vehicles **104**, **106** to decrease to a designated momentum, such as the momentum of another group of the vehicles **104**, **106** in the same vehicle system **100**, to within a designated range of the momentum of the other group of the vehicles **104**, **106** (e.g., within 1%, 3%, 5%, 10%, or another range), or another value. Alternatively, the operational settings may be determined to cause the momentum of one group of the vehicles **104**, **106** to increase to a designated momentum, such as the momentum of another group of the vehicles **104**, 106 in the same vehicle system 100, to within a designated range of the momentum of the other group of the vehicles 104, 106 (e.g., within 1%, 3%, 5%, 10%, or another range), or another value. Designating the operational settings to cause the momentum of different vehicles 104, 106 or vehicle groups in the same vehicle system 100 to be the same or within a designated range of each other can reduce the forces exerted on couplers between the vehicles 104, 106 and/or vehicle groups and/or can eliminate or reduce nodes in the vehicle system, and thereby improve parameters of the vehicle system.

When the tractive efforts and/or braking efforts $u_i(x), \ldots, u_n(x)$ are identified at one or more locations along the route 102 that reduce the parameters relative to the synchronous operational settings, the asynchronous operational settings that correspond to the identified the tractive efforts and/or braking efforts $u_i(x), \ldots, u_n(x)$ are determined. For example, the throttle settings and/or brake settings that are needed for each of the propulsion-generating vehicles 104 to provide the identified tractive efforts and/or braking efforts $u_i(x), \ldots, u_n(x)$ are determined, such as from a table, listing, previously determined relationship between the efforts and the settings, or the like. Flow of the method 200 then proceeds to 210.

At 210, a determination is made as to whether one or more of the asynchronous operational settings can be modified in order to achieve or improve upon a trip objective. As described above, a trip objective can include a reduction in fuel consumption, emission generation, and/or travel time. If one or more of the asynchronous operational settings can be changed in order to reduce fuel consumption, emission generation, and/or travel time (relative to not changing the asynchronous operational settings) while avoiding significant decreases in the improvement in vehicle handling (that is achieved by using the asynchronous operational settings), then the asynchronous operational settings may be modified. On the other hand, if changing the asynchronous operational settings would not result in achieving or improving upon a trip objective, then the asynchronous operational settings may not be changed.

FIG. 5 illustrates two relationships 500, 502 between different asynchronous operational settings and a parameter at two different locations along the route 102 (shown in FIG. 1) in accordance with one example. The relationships 500, 502 may each represent how a parameter (e.g., a coupler parameter representative of an amount of energy stored in one or more, or all, of the couplers 108 in the vehicle system 100 shown in FIG. 1) varies at each the two different locations if the operational setting (e.g., a throttle setting for a propulsion-generating vehicle 104) is changed. The relationships 500, 502 are shown alongside a horizontal axis 506 representative of the operational parameter and a vertical axis 508 representative of the parameter.

For example, the relationship 500 may represent how the parameter is expected to change if the operational setting is changed at a first location along the route 102. As shown in FIG. 5, a previous synchronous operational setting may be changed to an asynchronous operational setting at a first value 510 to cause the parameter to be minimized or otherwise reduced to a lower value 512 at the first location along the route 102. Changing the first value 510 of the asynchronous operational setting to a second value 514 may achieve or improve upon a trip objective, such as by reducing the throttle setting in order to reduce the amount of fuel consumed by the vehicle system 100. This change, however, also causes the parameter to be increased from the lower value 512 to an upper value 516.

The determination of whether to decrease the operational setting to the value 514 may be based on one or more thresholds. For example, if this change in operational setting results in a reduction in fuel consumption and/or a reduction in the amount of emissions generated that is greater than one or more designated threshold amounts, and the change does not result in the parameter increasing by more than a designated threshold amount from the lower value 512 to the upper value 516 and/or cause the vehicle system 100 to travel slower than a designated speed or produce less than a designated total power output, then the change may be implemented. If, however, the change results in a reduction in fuel consumption and/or emissions generation that is smaller than a threshold amount, the parameter increasing by more than a threshold amount, and/or the vehicle system 100 to travel slower than a designated speed and/or produce less than a designated total power, then the change may not be made to the previously identified asynchronous operational setting.

As another example, the relationship 502 may represent how the parameter is expected to change if the operational setting is changed at a different, second location along the route 102. As shown in FIG. 5, a previous synchronous operational setting may be changed to an asynchronous operational setting at a third value 518 to cause the parameter to be minimized or otherwise reduced to a lower value 520 at the second location along the route 102. As shown by the relationship 502, increasing or decreasing the operational setting will cause the parameter to increase. Increasing the operational setting may not be permitted as doing so may cause the vehicle system 100 to consume excess fuel and/or generate increased emissions. Therefore, the operational setting may be decreased. In one embodiment, the operational setting may be decreased until the parameter is increased by no more than a threshold amount or by no more than a designated threshold value. For example, the operational setting may be decreased until the lower value 520 of the parameter is increased to an upper limit 522 on the parameter.

Returning to the description of the method 200 shown in FIG. 2, at 210, if the asynchronous operational setting can be modified at one or more locations along the route 102 to achieve or improve upon a trip objective, then flow of the method 200 may proceed to 212. Otherwise, the method 200 may proceed to 214.

At 212, the asynchronous operational settings are modified at one or more locations along the route 102. For example, after determining the asynchronous operational settings and determining that the asynchronous operational settings can be changed to achieve or improve upon a trip objective, the asynchronous operational settings that can be changed are modified. As a result, the modified asynchronous operational settings that are so determined can provide at least the total power output that is dictated by the synchronous trip plan at various locations along the route 102, but also improve upon the handling of the vehicle system 100 relative to the synchronous trip plan and achieve one or more trip objectives relative to the synchronous trip plan.

At 214, the asynchronous operational settings (e.g., the asynchronous operational settings that were modified or that were not modified) are used to asynchronously control operations of the vehicle system 100. For example, the asynchronous operational settings can be used to autonomously control operations of the propulsion-generating vehicles 104 along the route 102. Alternatively, the asynchronous operational settings can be used to direct an operator to manually control operations of the propulsion-generating vehicles **104** along the route **102** according to the asynchronous operational settings.

FIG. **6** is a flowchart of another embodiment of a method **600** for operating the vehicle system **100** shown in FIG. **1**. The method **600** may be used in conjunction with the vehicle system **100**. For example, the method **600** may be used to identify asynchronous operational settings for the vehicle system **100** when no synchronous trip plan is available or is not used to derive the asynchronous operational settings.

At **602**, trip data representative of a trip to be traveled or currently being traveled by the vehicle system **100**, vehicle data representative of the vehicle system **100**, and/or route data representative of the route **102** of the trip are obtained. The data may be obtained from one or more memory devices disposed onboard and/or off-board of the vehicle system **100**, such as from a dispatch facility.

At **604**, parameters are calculated at one or more different locations along the route **102** of the trip. For example, one or more of the parameters described above can be estimated from a simulation of travel of the vehicle system **100** and/or from previous trips of the same or similar vehicle system **100** along the route **102**. In one embodiment, the terrain excitation parameter is estimated for travel of the vehicle system **100** over the route **102**. If throttle and/or brake settings are needed to determine the parameters, then default values, historical values (e.g., settings used during a previous trip over the route **102**), and/or other values may be used to estimate the parameters.

At **606**, one or more locations of interest along the route **102** are identified based on the parameters. A location of interest may represent a section of the route **102** that may be relatively difficult or complex to control operations of the vehicle system **100** while providing improved handling relative to one or more other sections of the route **102**. For example, a section of the route **102** having undulating terrain may be more difficult or complex to control the vehicle system **100** over with improved handling relative to the vehicle system **100** traveling over a relatively flat section of the route **102**. In one embodiment, the locations of interest are identified responsive to the parameters (that are calculated at **604**) exceeding one or more designated thresholds. For example, the locations along the route **102** where the parameters are calculated to be relatively large may be identified as locations of interest.

At **608**, a trip plan is created for the trip along the route **102**. For example, a trip plan having synchronous operational settings for the propulsion-generating vehicles **104** at various locations along the route **102** may be created. As described above, in one embodiment, the trip plan may be created using one or more embodiments of the subject matter described in the '354 Application. The trip plan may be created using the trip data, vehicle data, and/or route data and may reduce fuel consumed, emissions generated, and/or travel time for the trip relative to the vehicle system **100** traveling along the route **102** for the trip according to another, different trip plan having different synchronous operational settings (or relative to the vehicle system traveling according to a designated speed, such as at the speed limit or speed limits of the route).

In one embodiment, the trip plan may be created subject to one or more constraints placed on the operational settings used at the locations of interest. For example, a reduced speed limit (e.g., relative to a government or landowner-mandated speed limit) may be applied to the locations of interest and/or a minimum speed limit that the vehicle system **100** is required to maintain may be applied to the locations of interest. Alternatively or additionally, limitations on how often throttle and/or brake settings can be changed in the locations of interest can be placed on the trip plan. Other limitations on movements and/or control of the vehicle system **100** may be applied as well. The trip plan may then be created so that the synchronous operational settings of the trip plan abide by these restrictions on the locations of interest. For example, the trip plan may be created so that the vehicle system **100** is not directed to travel faster than upper speed limits or slower than minimum speed limits at the associated locations of interest. Other examples of constraints are described above, such as engine derating, notch delta penalties, limitations on how frequently group assignments can change, limitations on nodes, etc.

At **610**, total power outputs that are to be provided by the vehicle system **100** are determined at the locations along the route **102**. For example, similar to **206** of the method **200** shown in FIG. **2**, the total power outputs that are to be provided, in the aggregate, by the propulsion-generating vehicles **104** in the vehicle system **100** may be determined for at least some, or all, the same locations at which the parameters are determined at **204**. Alternatively, an operator of the vehicle system **100** can designate or input the total power output directly via throttle position. The operator can provide the total power output so that the method **600** can determine the operational settings that result in providing the total power output provided by the operator.

At **612**, asynchronous operational settings for the vehicle system **100** are determined. For example, similar to **208** of the method **200**, the total power outputs can be divided among the propulsion-generating vehicles **104** in the vehicle system **100** at the locations and based on the parameters by determining different operational settings for different vehicles **104**, **106** at these locations. The total power outputs of the synchronous trip plan may be divided among the propulsion-generating vehicles **104** by designating the same throttle and/or brake settings for each of the propulsion-generating vehicles **104**. Using the parameters that are determined at the locations along the route **102**, the same total power outputs at these locations can be divided among the propulsion-generating vehicles **104** by designating different throttle and/or brake settings for the propulsion-generating vehicles **104**.

At **614**, a determination is made as to whether one or more of the asynchronous operational settings can be modified in order to achieve or improve upon a trip objective. For example, similar to **210** of the method **200**, if one or more of the asynchronous operational settings can be changed in order to reduce fuel consumption, emission generation, and/or travel time (relative to not changing the asynchronous operational settings) while avoiding significant decreases in the improvement in vehicle handling (that is achieved by using the asynchronous operational settings), then the asynchronous operational settings may be modified. On the other hand, if changing the asynchronous operational settings would not result in achieving or improving upon a trip objective, then the asynchronous operational settings may not be changed. If the asynchronous operational setting can be modified at one or more locations along the route **102** to achieve or improve upon a trip objective, then flow of the method **600** may proceed to **616**. Otherwise, the method **600** may proceed to **614**.

At **616**, the asynchronous operational settings are modified at one or more locations along the route **102**. For example, similar to **212** of the method **200**, after determining the asynchronous operational settings and determining that the asynchronous operational settings can be changed to achieve or improve upon a trip objective, the asynchronous operational settings that can be changed are modified. As a result, the modified asynchronous operational settings that are so determined can provide at least the total power output that is dictated by the synchronous trip plan at various locations along the route **102**, but also improve upon the handling of the vehicle system **100** relative to the synchronous trip plan and achieve one or more trip objectives relative to the synchronous trip plan.

At **618**, the asynchronous operational settings are used to asynchronously control operations of the vehicle system **100**. For example, similar to **214** of the method **200**, the asynchronous operational settings can be used to autonomously control operations of the propulsion-generating vehicles **104** along the route **102**. Alternatively, the asynchronous operational settings can be used to direct an operator to manually control operations of the propulsion-generating vehicles **104** along the route **102** according to the asynchronous operational settings.

In another embodiment, instead of determining the asynchronous operational settings from a synchronous trip plan and/or determining the asynchronous operational settings at the locations associated with larger parameters, a trip plan may be created in order to "optimize" (e.g., improve) the handling of the vehicle system **100** and one or more trip objectives. For example, a trip plan may be created from the trip data, vehicle data, route data, and/or parameters, with the trip plan decreasing the parameters at locations along the route **102** while also reducing fuel efficiency, reducing the generation of emissions, and/or reducing travel time of the trip, as described herein. For example, the trip plan may be created a single time with the objectives of improving both handling and improving one or more objectives of the trip.

FIG. **7** is a flowchart of another embodiment of a method **700** for operating the vehicle system **100** shown in FIG. **1**. The method **700** may be used in conjunction with the vehicle system **100**. For example, the method **700** may be used to identify asynchronous operational settings for the vehicle system **100** when no synchronous trip plan is available or is not used to derive the asynchronous operational settings.

At **702**, trip data representative of a trip to be traveled or currently being traveled by the vehicle system **100**, vehicle data representative of the vehicle system **100**, and/or route data representative of the route **102** of the trip are obtained. The data may be obtained from one or more memory devices disposed onboard and/or off-board of the vehicle system **100**, such as from a dispatch facility. A trip plan formed from synchronous operational settings for the propulsion-generating vehicles **104** may be created from the trip data, vehicle data, and/or route data, as described above, or received from an off-board source. Alternatively, the route data alone may be obtained at **702**.

At **704**, natural forces that are to be exerted on the vehicle system **100** during travel along the route **102** during the trip are estimated. The natural forces exerted on the vehicle system **100** may be parameters that are used to determine operational settings for the propulsion-generating vehicles **104** and to improve the handling of the vehicle system **100**. The natural forces include the forces exerted on the couplers **108** (e.g., as predicted by a rigid rope model of the vehicle system **100** when only the gravitational forces on the vehicle system **100** are considered). These estimated natural forces may be dependent on the terrain and may be independent of the propulsion-generating vehicles **104** (e.g., independent of the tractive efforts generated by the vehicles **104**), drag forces, air-brake forces, and/or other operational parameters. The natural forces may be estimated for one or more couplers **108** disposed between propulsion-generating vehicles **104** in the vehicle system **100**. In one embodiment, the natural forces are determined for a segment of the vehicle system **100** that includes one or more non-propulsion generating vehicles **106** that are disposed between and that interconnect two or more propulsion-generating vehicles **104**. Alternatively or additionally, the natural forces may be determined for the entire vehicle system **100** and/or for multiple segments of the vehicle system **100**.

The natural forces exerted on couplers **108** may be estimated using route data that is representative of the route **102** (e.g., curvature and/or grade), and/or vehicle data that is representative of the size (e.g., mass) of the vehicle system **100** and/or a segment of the vehicle system **100**:

$$F_{i-1}-F_i=m_i g_i+m_i\dot{v} \quad \text{(Equation \#15)}$$

where F_i represents the natural force exerted on the i^{th} coupler **108** in the vehicle system **100**, F_{i-1} represents the natural force exerted on the $(i-1)^{th}$ coupler **108** in the vehicle system **100**, m_i represents the mass of the i^{th} vehicle **104** or **106**, g_i represents the mean, average, or effective grade of the route **102** beneath the vehicle system **100**, and $\dot{v}$ represents the acceleration of the vehicle system **100**. The acceleration ($\dot{v}$) may be the acceleration that is caused by gravitational force and can be represented as:

$$\dot{v}=\frac{\sum_{i=1}^{N} m_i g_i}{\sum_{i=1}^{N} m_i} \quad \text{(Equation \#16)}$$

As a result, the natural force exerted on the i^{th} coupler **108** may be defined as:

$$F_i=\sum_{j=1}^{i} m_j g_j + m_j\dot{v} \quad \text{(Equation \#17)}$$

If the natural force is positive at a coupler **108** (e.g., greater than zero), the natural force can indicate that gravity tends to stretch the coupler **108**. Conversely, if the natural force is negative at the coupler **108** (e.g., less than zero), the natural force can indicate that gravity tends to compress the coupler **108**. The estimated natural forces can be used to determine a differential power (or effort) between the propulsion-generating vehicles **104** on opposite sides of the coupler **108** (but not necessarily directly connected to the coupler **108**).

In one embodiment, the natural forces are used to determine a bunching power for the propulsion-generating vehicles **104** that are on opposite sides of the coupler **108**. The bunching power can represent the total differential power output with respect to a synchronous power output that is to be generated by these propulsion-generating vehicles **104**. For example, the bunching power can represent a total difference between the power output of the vehicles (as calculated using one or more methods described herein) and the power output of the vehicles if the vehicles were using synchronous operational settings. As one example, the bunching power can be expressed as:

$$B=\begin{cases} K(p-n) & \text{if } |p-n|>t \\ 0 & \text{otherwise} \end{cases} \quad \text{(Equation \#18)}$$

where k represents a spring constant of the spring model of the coupler **108**, p represents a positive natural force (e.g., the maximum positive natural force) exerted on the coupler **108**, n represents an absolute value of a negative natural force (e.g., the maximum absolute negative natural force) exerted on the coupler **108**, B represents an estimated bunching effort or power, and t represents a designated threshold.

As a result, if the positive natural force p is larger than the threshold t plus the absolute negative natural force n, then the estimated bunching effort or power B is proportional to the difference between the positive natural force and the absolute value of the negative natural force. If the absolute negative natural force n is larger than the threshold t plus the positive natural force p, then the estimated bunching effort or power B is proportional to the difference between the positive natural force and the absolute value of the negative natural force. Otherwise, the estimated bunching effort or power B is set to zero.

When the natural force on a coupler **108** is larger than the natural compressive force on the coupler **108**, the bunching effort B is positive, which can indicate that the vehicle system **100** can be compressed to compensate for the gravity stretching the vehicle system **100**. Similarly, when the natural compressive force is larger than the natural stretch force on the coupler **108**, the bunching effort B is negative, which can indicate that the vehicle system **100** can be stretched to compensate for the natural forces.

At **706**, a determination is made as to whether the estimated natural force on one or more couplers **108** exceeds a designated threshold. For example, the natural force that is estimated to be exerted on a coupler **108** at a location along the route **102** may be compared to a threshold. If the natural force exceeds a designated threshold, then the natural force may be sufficiently large to warrant designating different operational settings (e.g., asynchronous operational settings) for the propulsion-generating vehicles **104** disposed on opposite sides of the coupler **108** in order to compensate for the natural force. Such relatively large natural forces may decrease handling of the vehicle system **100** and may be undesirable for the control of the vehicle system **100**. If the estimated natural force indicates that the coupler **108** may experience a relatively large tensile force at a location along the route **102**, then the operational settings of the propulsion-generating vehicles **104** may be designated to compress the coupler **108**. Alternatively, if the estimated natural force indicates that the coupler **108** may experience a relatively large compressive force at a location along the route **102**, then the operational settings of the propulsion-generating vehicles **104** may be designated to stretch the coupler **108**. As a result, flow of the method **700** may proceed to **708**.

On the other hand, if the estimated natural force does not exceed the threshold, then the natural force may not be sufficiently large to warrant designating asynchronous operational settings for the propulsion-generating vehicles **104** disposed on opposite sides of the coupler **108** in order to compensate for the natural force. For example, if the estimated natural force indicates that the coupler **108** may experience a relatively small tensile or compressive force, then the natural force may not significantly impact the handling of the vehicle system **100** in a negative or undesirable manner. As a result, flow of the method **700** may proceed to **710**.

At **708**, asynchronous operational settings for the propulsion-generating vehicles **104** disposed on opposite sides of the coupler **108** are determined. The asynchronous operational settings may be based on the bunching effort or horsepower. For example, the asynchronous operational settings may be determined so that the total (e.g., aggregate) power output that is to be generated by the propulsion-generating vehicles **104** on opposite sides of the coupler **108** is the bunching effort or horsepower. The bunching effort or horsepower may be the effort (B) determined above using Equation #18 or another effort or horsepower that reduces the estimated natural force on the coupler **108**. The asynchronous operational settings may be used to control operations of the propulsion-generating vehicles **104**, such as by automatically implementing the asynchronous operational settings or by directing an operator of the vehicle system **100** to manually implement the asynchronous operational settings at the location associated with the estimated natural force on the coupler **108**.

At **710**, the propulsion-generating vehicles **104** disposed on opposite sides of the coupler **108** for which the natural force is estimated are controlled using synchronous (e.g., the same) operational setting, such as the same throttle settings. For example, because the estimated natural force may be relatively small, the synchronous operational settings of a trip plan may be used for the propulsion-generating vehicles **104** instead of changing the operational settings to asynchronous operational settings.

FIG. **8** is a schematic diagram of one embodiment of a propulsion-generating vehicle **800**. The propulsion-generating vehicle **800** may represent one or more of the propulsion-generating vehicles **104** shown in FIG. **1**. The propulsion-generating vehicle **800** includes a propulsion system **802**, which can include one or more engines, motors, brakes, batteries, cooling systems (e.g., radiators, fans, etc.), and the like, that operate to generate power output to propel the vehicle **800**. One or more input and/or output devices **804** ("Input/Output **804**" in FIG. **8**), such as keyboards, throttles, switches, buttons, pedals, microphones, speakers, displays, and the like, may be used by an operator to provide input and/or monitor output of one or more systems of the vehicle **800**.

The propulsion-generating vehicle **800** includes an onboard control system **806** that controls operations of the propulsion-generating vehicle **800**. For example, the control system **806** may determine the asynchronous operational settings for the vehicle **800** and at least one other propulsion-generating vehicle in the same vehicle system. Alternatively, the control system **806** may entirely or partially be disposed off-board the vehicle **800**, such as at a dispatch facility or other facility. The vehicle system **100** (shown in FIG. **1**) that may include the propulsion-generating vehicle **800** may include only a single vehicle **800** having the control system **806** that receives or determines the asynchronous operational settings described herein. Alternatively, the vehicle system **100** may have multiple vehicles **800** with the control systems **806** that receive or determine the asynchronous operational settings.

Other propulsion-generating vehicles in the vehicle system **100** may be controlled based on the asynchronous operational settings that are communicated from the propulsion-generating vehicle **800** that has the control system **806** in order to control the operations of the other propulsion-generating vehicles. Alternatively, several propulsion-generating vehicles **800** in the vehicle system **100** may include the control systems **806** and assigned priorities among the control systems **806** may be used to determine which control system **806** controls operations of the propulsion-generating vehicles **800**.

The control system **806** is communicatively coupled with a communication unit **808**. The communication unit **808** communicates with one or more off-board locations, such as another vehicle (e.g., another propulsion-generating vehicle in the same vehicle system **100**, a dispatch facility, another vehicle system, or the like). The communication unit **808** can communicate via wired and/or wireless connections (e.g., via radio frequency). The communication unit **808** can include a wireless antenna **810** and associated circuitry and software to communicate wirelessly. Additionally or alternatively, the communication unit **808** may be connected with a wired connection **812**, such as one or more buses, cables, and the like, that connect the communication unit **808** with another vehicle in the vehicle system or consist (e.g., a trainline, multiple unit cable, electronically controlled pneumatic brake line, or the like). The communication unit **808** can be used to communicate (e.g., transmit and/or receive) a variety of information described herein. For example, the communication unit **808** can receive the trip plan having synchronous operational settings, trip data, route data, vehicle data, operational settings from another propulsion-generating vehicle **800** and/or another control unit **806**, and/or other information that is used to determine the parameters and asynchronous operational settings described herein. The communication unit **808** can transmit asynchronous operational settings, such as the asynchronous operational settings determined by the control system **806** and/or received from an off-board source, to one or more other propulsion-generating vehicles in the vehicle system **100**. These transmitted asynchronous operational settings are used to direct the operations of the other propulsion-generating vehicles.

The control system **806** includes units that perform various operations. The control system **806** and one or more of the units may represent a hardware and/or software system that operates to perform one or more functions described herein. For example, the control system **806** and/or the illustrated units may include one or more computer processor(s), controller(s), or other logic-based device(s) that perform operations based on instructions stored on a tangible and non-transitory computer readable storage medium. Alternatively, the control system **806** and/or the units may include one or more hard-wired devices that perform operations based on hard-wired logic of the devices. The control system **806** and/or the units shown in FIG. **8** may represent the hardware that operates based on software or hardwired instructions, the software that directs hardware to perform the operations, or a combination thereof.

In the illustrated embodiment, the control system **806** includes an energy management unit **814** that receives input to create a trip plan. For example, the energy management unit **814** may receive trip data, vehicle data, and/or route data in order to create a trip plan having synchronous operational settings. As described above, such a trip plan may be used to determine asynchronous operational settings to improve the handling of the vehicle system **100** and/or to identify locations of interest along the route **102** where the asynchronous operational settings are to be determined in order to improve handling. Additionally or alternatively, the energy management unit **814** may create the trip plan with asynchronous operational settings, and may do so by attempting to reduce one or more of the parameters while also reducing the fuel consumed by the vehicle system **100**, the emissions generated by the vehicle system **100**, and/or the travel time to complete the trip. For example, the energy management unit **814** may determine the asynchronous operational settings for the propulsion-generating vehicles **104**, **800** of the vehicle system **100** at one or more locations along the route **102** in order to reduce the parameters, fuel consumed, emissions generated, and/or travel time relative to another trip plan for the same trip and same vehicle system **100** that includes synchronous operational settings at one or more of the locations. Optionally, the energy management unit **814** that determines the synchronous and/or asynchronous trip plan may be disposed off-board of the vehicle **800** and may communicate the trip plan to the control system **806**.

An effort determination unit **816** examines the trip plan to determine the total power output demanded from the propulsion-generating vehicles **104**, **800** in the vehicle system **100** by the trip plan at one or more locations along the route **102**. For example, the effort determination unit **816** can identify the estimated or anticipated power outputs of each of the propulsion-generating vehicles based on the designated operational settings (e.g., throttle notch positions) in the trip plan and then sum these power outputs to determine the total power output to be provided by the vehicle system **100**.

A handling unit **818** calculates one or more parameters described above. The handling unit **818** can estimate the values of the parameters at one or more locations along the route **102**, as described above. The handling unit **818** can determine these parameters using the operational settings designated by the trip plan, also as described above.

A post processing unit **820** determines the asynchronous operational settings for two or more of the propulsion-generating vehicles in the vehicle system. For example, the post processing unit **820** can examine the total power outputs derived from the trip plan by the effort determination unit **816** and the parameters estimated by the handling unit **818**. The post processing unit **820** may then determine asynchronous operational settings that improve handling of the vehicle system **100** (e.g., by reducing one or more of the parameters) while providing the total power outputs of the vehicle system **100**, as described above. The post processing unit **820** may optionally determine if the asynchronous operational settings can be modified to achieve or improve upon one or more trip objectives, such as fuel consumption, travel time, emissions generation, and the like.

A controller unit **822** forms instructions that are based on the asynchronous operational settings to control movement of the propulsion-generating vehicle **800** and/or one or more other propulsion-generating vehicles in the vehicle system **100**. For example, the controller unit **822** can create one or more data signals or packets that represent the asynchronous operational settings determined by the post processing unit **820**. These instructions may be communicated to the propulsion system **802** of the vehicle **800** and/or to similar propulsion systems of other propulsion-generating vehicles in the same vehicle system **100** to autonomously control movements of the propulsion-generating vehicles. The propulsion systems that receive the instructions may automatically implement the throttle and/or brake settings dictated by the asynchronous operational settings. Optionally, the instructions may be communicated to the one or more output devices **804** of the vehicle **800** and/or one or more similar output devices on other propulsion-generating vehicles in the vehicle system **100** to direct one or more operators on how to manually change throttle and/or brake settings of the propulsion-generating vehicles according to the asynchronous operational settings.

In one embodiment, the controller unit **822** may determine the actual speed of the propulsion-generating vehicle **800** and/or one or more other propulsion-generating vehicles in the vehicle system **100**. For example, the controller unit **822** may receive or measure data from the propulsion system

802 that represents the actual speed of the propulsion-generating vehicle **800**. This data may be obtained from a speed sensor that is included in the propulsion system **802**. Additionally or alternatively, the controller unit **822** may receive similar data from other propulsion-generating vehicles in the vehicle system **100**.

The controller unit **822** can compare the actual speed of the propulsion-generating vehicle **800**, the other propulsion-generating vehicles, and/or the vehicle system **100** (e.g., which may be represented by the actual speeds of one or more of the propulsion-generating vehicles) to a speed that is designated by a trip plan (e.g., a synchronous or asynchronous trip plan). If the actual speed differs from the designated speed, the controller unit **822** may identify a change in throttle settings and/or brake settings for one or more of the propulsion-generating vehicles in the vehicle system **100** that can be used to reduce or eliminate the difference between the actual and designated speeds. The controller unit **822** may direct (e.g., by transmitting instructions) to one or more of the propulsion-generating vehicles to change the respective throttle settings and/or brake settings to reduce or eliminate the difference between the actual and designated speeds. The controller unit **822** may also determine a corresponding change in the throttle settings and/or brake settings of one or more other propulsion-generating vehicles in order to maintain improved handling of the vehicle system **100**. For example, if a group bunching effort is being maintained between two or more propulsion-generating vehicles or consists of propulsion-generating vehicles, then a change in the throttle settings of one vehicle or consist to cause the actual speed to match the designated speed may require a change in the throttle settings of another vehicle or consist in order to maintain the group bunching effort. The controller unit **822** can identify this change in the settings of the other vehicle or consist and communicate the change to the other vehicle or consist for implementation.

Although connections between the components in FIG. **8** are not shown, two or more (or all) of the illustrated components may be connected by one or more wired and/or wireless connections, such as cables, busses, wires, wireless networks, and the like.

In one embodiment, a method (e.g., for determining operational settings for a vehicle system having multiple vehicles connected with each other by couplers to travel along a route) includes identifying total power outputs to be provided by propulsion-generating vehicles of the vehicles in the vehicle system. The total power outputs are determined for different locations of the vehicle system along the route. The method also includes calculating parameters of the vehicle system at one or more of the different locations along the route. The parameters are representative of at least one of forces exerted the couplers, energies stored in the couplers, relative velocities of neighboring vehicles of the vehicles in the vehicle system, or natural forces exerted on one or more segments of the vehicle system between two or more of the propulsion-generating vehicles. The method also includes determining asynchronous operational settings for the propulsion-generating vehicles at the different locations along the route. The asynchronous operational settings represent different operational settings for the propulsion-generating vehicles that cause the propulsion-generating vehicles to provide at least the total power outputs at the respective different locations while changing the parameters of the vehicle system to one or more designated values at the different locations along the route. The method further includes communicating the asynchronous operational settings to the propulsion-generating vehicles in order to cause the propulsion-generating vehicles to implement the asynchronous operational settings at the different locations.

In another aspect, the asynchronous operational settings are determined by identifying the different operational settings for the propulsion-generating vehicles that reduce the parameters relative to different parameters associated with using synchronous operational settings for the propulsion-generating vehicles at the respective different locations to provide the total power outputs at the respective different locations.

In another aspect, the parameters include coupler parameters representative of at least one of the forces exerted on the couplers or the energies stored in the couplers.

In another aspect, the parameters include terrain excitation parameters representative of at least one of grades of the route at the respective different locations, masses of one or more of the vehicles in the vehicle system at the respective different locations, or tractive efforts provided by one or more of the propulsion-generating vehicles at the respective different locations.

In another aspect, identifying one or more nodes in the vehicle system, the one or more nodes representative of an estimated force exerted on a coupler that has an absolute value that is less than a designated threshold. The parameters include node parameters representative of at least one of a number of the nodes in the vehicle system or a rate of movement of the nodes in the vehicle system.

In another aspect, the parameters include neighboring velocity parameters representative of the relative velocities of neighboring vehicles of the vehicles in the vehicle system and determined by identifying estimated differences in estimated speed between the neighboring vehicles in the vehicle system.

In another aspect, the method includes modifying the asynchronous operational settings to reduce at least one of an amount of fuel to be consumed by the vehicle system, an amount of emissions to be generated by the vehicle system, or a travel time of the vehicle system for the trip while maintaining a resulting increase in the parameters below a designated threshold.

In another aspect, the parameters include the natural forces that are representative of one or more tensile or compressive forces exerted on the one or more segments of the vehicle system from a gravitational force.

In another aspect, the total power outputs to be provided by propulsion-generating vehicles are identified from a synchronous trip plan that designates synchronous operational settings for the propulsion-generating vehicles at the locations. When the vehicle system travels along the route according to the synchronous trip plan causes the vehicle system to reduce at least one of fuel consumed, emissions generated, or travel time relative to another, different trip plan that designates one or more other, different synchronous operational settings.

In another aspect, the method also includes at least one of autonomously implementing the asynchronous operational settings at the different locations or communicating the asynchronous operational settings for the vehicle system at one or more of a current location or an upcoming location to an operator of the vehicle system for the operator to manually implement the asynchronous operational settings.

In another aspect, the method also includes modifying the one or more designated values to which the parameters are changed based on at least one of a terrain of the route, a mass distribution of the vehicle system, a type of the vehicle system, or a type of the couplers in the vehicle system.

In one embodiment, a system (e.g., a control system for a vehicle system) includes an effort determination unit configured to identify total power outputs to be provided by a vehicle system that includes multiple vehicles connected with each other by couplers to travel along a route. The effort determination unit also is configured to identify the total power outputs to be provided by propulsion-generating vehicles of the vehicles in the vehicle system at different locations of the vehicle system along the route. The system includes a handling unit configured to calculate parameters of the vehicle system at one or more of the different locations along the route. The parameters are representative of at least one of forces exerted the couplers, energies stored in the couplers, relative velocities of neighboring vehicles of the vehicles in the vehicle system, or natural forces exerted on one or more segments of the vehicle system between two or more of the propulsion-generating vehicles. The system includes a processing unit configured to determine asynchronous operational settings for the propulsion-generating vehicles at the different locations along the route. The asynchronous operational settings represent different operational settings for the propulsion-generating vehicles that cause the propulsion-generating vehicles to provide at least the total power outputs at the respective different locations while changing the parameters of the vehicle system to one or more designated values at the different locations along the route. The asynchronous operational settings are configured to be communicated to the propulsion-generating vehicles in order to cause the propulsion-generating vehicles to implement the asynchronous operational settings at the different locations.

In another aspect, the processing unit is configured to identify the different operational settings for the propulsion-generating vehicles that reduce the parameters relative to different parameters associated with using synchronous operational settings for the propulsion-generating vehicles at the respective different locations to provide the total power outputs at the respective different locations.

In another aspect, the parameters include coupler parameters representative of at least one of the forces exerted on the couplers or the energies stored in the couplers.

In another aspect, the parameters include terrain excitation parameters based on at least one of grades of the route at the respective different locations, masses of one or more of the vehicles in the vehicle system at the respective different locations, or tractive efforts provided by one or more of the propulsion-generating vehicles at the respective different locations.

In another aspect, the handling unit is configured to identify one or more nodes in the vehicle system. The one or more nodes are representative of an estimated force exerted on a coupler that has an absolute value that is less than a designated threshold. The parameters include node parameters representative of at least one of a number of the nodes in the vehicle system or a rate of movement of the nodes in the vehicle system.

In another aspect, the parameters include neighboring velocity parameters representative of the relative velocities of neighboring vehicles of the vehicles in the vehicle system and determined by identifying estimated differences in estimated speed between the neighboring vehicles in the vehicle system.

In another aspect, the processing unit is configured to modify the asynchronous operational settings to reduce at least one of an amount of fuel to be consumed by the vehicle system, an amount of emissions to be generated by the vehicle system, or a travel time of the vehicle system for the trip while maintaining a resulting increase in the parameters below a designated threshold.

In one embodiment, a method (e.g., for determining operational settings for a vehicle system having two or more propulsion-generating vehicles coupled with each other by one or more non-propulsion generating vehicles) includes obtaining route data and vehicle data. The route data is representative of one or more grades of a route at one or more locations along the route that is to be traveled by the vehicle system. The vehicle data is representative of a size of the one or more non-propulsion generating vehicles disposed between the propulsion-generating vehicles. The method also includes calculating one or more estimated natural forces that are to be exerted on couplers connected with the one or more non-propulsion generating vehicles of the vehicle system at the one or more locations along the route. The one or more estimated natural forces are based on the size of the one or more non-propulsion generating vehicles and the one or more grades of the route at the one or more locations along the route. The method also includes determining asynchronous operational settings to be implemented by the two or more propulsion-generating vehicles at the one or more locations along the route. Implementing the asynchronous operational settings by the two or more propulsion-generating vehicles reduces one or more actual natural forces that are actually exerted on the couplers to forces that are smaller than the one or more estimated natural forces when the vehicle system travels over the one or more locations along the route.

In another aspect, when the one or more estimated natural forces are tensile forces, the asynchronous operational settings instruct the two or more propulsion-generating vehicles to implement at least one of different throttle settings or different brake settings to compress the couplers connected with the non-propulsion generating vehicles.

In another aspect, when the one or more estimated natural forces are compressive forces, the asynchronous operational settings instruct the two or more propulsion-generating vehicles to implement at least one of different throttle settings or different brake settings to stretch the couplers connected with the non-propulsion generating vehicles.

In one embodiment, a method (e.g., for determining operational settings of a vehicle system) includes obtaining route data and vehicle data. The route data is representative of one or more grades of a route at one or more locations along the route that is to be traveled by a vehicle system having two or more propulsion-generating vehicles coupled with each other by one or more non-propulsion generating vehicles. The vehicle data is representative of a size of the one or more non-propulsion generating vehicles disposed between the propulsion-generating vehicles. The method also includes calculating parameters of the vehicle system at one or more different locations along the route based on the route data and the vehicle data. The parameters are representative of at least one of forces expected to be exerted the couplers, energies expected to be stored in the couplers, expected relative velocities of neighboring vehicles of the vehicles in the vehicle system, or expected natural forces exerted on one or more segments of the vehicle system between two or more of the propulsion-generating vehicles. The method further includes determining asynchronous operational settings to be implemented by the two or more propulsion-generating vehicles at the one or more locations along the route based on the parameters. The asynchronous operational settings are determined by identifying a combination of the asynchronous operational settings at the different locations along the route that result in the parameters being decreased to one or more designated limits.

Additional inventive subject matter described herein relates to ways of determining the asynchronous operational settings described above for a current or upcoming trip of a vehicle system. Specifically, methods of computing power and/or brake settings (also called notches) to propulsion-generating vehicles in the vehicle system in order to obtain improved train handling (relative to operating the vehicle system in another manner) are disclosed. In one aspect, the vehicle system is operated as a distributed power (DP) vehicle system. The vehicle system includes propulsion-generating vehicles placed at different locations in the vehicle system, and operating these propulsion-generating vehicles using different operational settings (e.g., different notches) at the same time. As described above, the propulsion-generating vehicles can be divided into groups in the vehicle system. In one example, these groups may be identified by placing one or more virtual "fences" between the different groups of propulsion-generating vehicles. A fence can be used to demarcate different groups of propulsion-generating vehicles, which can be referred to as consists. The propulsion-generating vehicles in the different groups are allowed (but not required) to have different operational settings (e.g., notches). For example, the vehicles in the same group can have the same operational setting, or notch, at a given time.

In one embodiment, the system and method described herein uses model predictive control (MPC) to determine the time and/or location along a route being traveled by the vehicle system to change which vehicles are included in the different groups to improve parameters of the vehicle system while satisfying other constraints (e.g., limitations on the frequency of changes in which vehicles are in which groups, bunching horsepower at the time of movement, and the like). MPC can include calculating or estimating parameters for the vehicle system at different locations and/or times along a route for an upcoming portion of a trip. These parameters may be calculated or estimated multiple times for the same location of the vehicle system and/or time along the trip, with different parameters calculated for different vehicle groups and/or fence positions. The parameters are predicted for an upcoming trip (e.g., prior to the vehicle system beginning to move for the trip) and/or for an upcoming segment of the trip (e.g., while the vehicle system is moving during the trip). Different sequences of changes to the vehicle groups and/or fence positions may be examined and compared with each other to identify the sequence or sequences that improve (e.g., increase or reduce, as appropriate) the parameters the most, more than one or more other sequences (but not necessarily all other sequences), or by at least a designated threshold amount.

In another embodiment, the times and/or locations where changes in which vehicles are included in which groups (also referred to as movement points or change points) can be found by examining an entire planned trip of the vehicle system. Alternatively, other techniques can be used.

In another embodiment, the movement points or change points are determined by using a "categorize and merge" technique. In this technique, each movement point is categorized as either TBD (e.g., the fence position can be in any location in the vehicle system or the vehicles may be in any group) or a selected position (e.g., a specific fence position in the vehicle system or the vehicles are in specific groups). The category TBD is selected when the group assignments of the vehicles do not differ significantly from each other in benefit. Otherwise, the group assignments of the vehicles with the most significant benefit, or that has a more significant benefit than one or more other groups of the vehicles, is selected. Then, an iterative searching technique is used to merge or split TBD segments into selected group assignments of the vehicles to satisfy the constraints. As used herein, the term "group assignments" refers to a state of the vehicles, such as an identification of which vehicles are included in which groups at a given or selected time.

The subject matter described herein solves a problem of ensuring improved automatic handling of the vehicle system in several manners, including by making use of asynchronous distributed power operation (e.g., by allowing different propulsion-generating vehicles in a vehicle system to have different power settings). Additionally, the subject matter changes which vehicles are included in which groups within the vehicle system to further improve train handling. The change in which vehicles are included in which groups can be performed by moving locations of the virtual fences. While some vehicle systems have been using empirical "rules of thumb" and heuristics to control vehicle systems and keep the vehicle systems bunched so that slack action in the vehicle system does not run out, these rules usually lack physical or mathematical justification. Moreover, these rules rapidly become complicated to use for a human operator (even more so if the number of groups or fences increases), who must control speed, brakes, and other variables in addition to modulating multiple notches to obtain acceptable handling of the vehicle system. Additionally, it can be difficult for an operator to determine deviations from a synchronous plan, based on the distribution of weight in the vehicle system, terrain properties, and speed.

FIG. **9** is a schematic illustration of another embodiment of a vehicle system **900**. The vehicle system **900** includes several vehicles **904**, **906** that are mechanically connected with each other to travel along a route **902**. The vehicles **904** (e.g., the vehicles **904**A-D) represent propulsion-generating vehicles, such as vehicles that generate tractive effort or power in order to propel the vehicle system along the route **902**. In an embodiment, the propulsion-generating vehicles can represent rail vehicles such as locomotives, but alternatively can represent another type of vehicle. The vehicles **906** (e.g., the vehicles **906**A-F) represent non-propulsion generating vehicles, such as vehicles that do not generate tractive effort or power. In an embodiment, the non-propulsion generating vehicles can represent rail cars or another type of vehicle. The route can be a body, surface, or medium on which the vehicle system travels, such as a track formed from one or more rails, or another type of route. The number and arrangement of the vehicles **904**, **906** is provided as one example, and other numbers and/or arrangements of the propulsion-generating vehicles and/or the non-propulsion generating vehicles may be used.

The vehicle system includes several vehicle consists **910** (e.g., consists **910**A-C) formed from one or more propulsion-generating vehicles. In the illustrated example, a lead consist **910**A includes the propulsion-generating vehicles **904**A, **904**B, a middle consist **910**B includes the propulsion-generating vehicle **904**C, and a remote consist **910**C includes the propulsion-generating vehicle **904**D. Optionally, a larger or fewer number of propulsion-generating vehicles may be included in one or more of the consists and/or a larger or fewer number of consists may be included in the vehicle system. The consists may be separated from each other by one or more non-propulsion generating vehicles.

A virtual fence **912** is shown in different locations in the vehicle system in FIG. **9**. In a first position, the virtual fence is between the lead consist and the middle consist. In a different, second position, the virtual fence is between the middle consist and the remote consist. The fence can move between these or other locations in the vehicle system as the vehicle system travels along the route. As the fence is moved, the propulsion-generating vehicles and/or the non-propulsion-generating vehicles can be included in (e.g., assigned to) different groups, with the vehicles in the same group using the same operational settings, such as the same throttle notch settings, same brake settings, or the like. For example, in a group of propulsion-generating vehicles, the propulsion-generating vehicles may use the same throttle notch settings. In a group of non-propulsion-generating vehicles and/or propulsion-generating vehicles, the same brake settings may be used. Different vehicles may be assigned to different groups without physically moving or changing the relative positions of the vehicles in the vehicle system. For example, a single virtual fence **912** may change positions between the two positions shown in FIG. **9**. Without moving any vehicle in the vehicle system, different vehicles may be assigned to different groups. For example, when the fence **912** is between the vehicles **904**B and **906**A, then the vehicles **904**A, **904**B can be assigned to one group while the vehicles **904**C, **904**D are assigned to a different group. Moving the fence **912** to another position (e.g., between the vehicles **904**C and **906**C can cause the vehicles **904**A, **904**B, and **904**C to be assigned to one group and the vehicle **904**D to be assigned to a different group without changing the location or order of the vehicles **904**A-E within the vehicle system **100**.

The fence can move between the positions of consists, and not the positions of the propulsion-generating vehicles within a consist, and the propulsion-generating vehicles on opposite sides of the fence can operate using different control signals. When the fence moves from time to time, the configuration of the groups changes, which can result in the change of the tractive effort generated along the length of the vehicle system, as well as the forces within the vehicle system.

While only a single fence is shown in FIG. **9**, alternatively, the vehicle system may operate using plural different fences. The description herein should not be construed to be limited to using only a single fence. Plural different fences may be used. Optionally, the vehicle system may operate using different numbers of fences at different times and/or locations along the route. The number of permitted fences or their possible locations may be referred to as a fence restriction or a group assignment restriction, and can indicate how many fences and/or vehicle groups are allowed at an associated time and/or location along the route or where they may be placed (e.g., inter- and/or intra-consist). The number of permitted fences and/or vehicle groups may be change as a function of time, location, and/or operator input. For example, different numbers of fences and/or vehicle groupings may be permitted at different times during a trip, at different locations along a route, and/or as selected by an operator of the vehicle system. For example, during a first time period and/or during movement over a first segment of the route, the vehicle system may operate using a single fence, during a different, second time period and/or during movement over a different, second segment of the route, the vehicle system may operate using two or more fences. Alternatively, the vehicle system may not use any virtual fences, but instead may operate by associating the propulsion-generating vehicles with different groups at different times and/or locations along the route.

For example, when the fence is located at a lead-middle position (e.g., between the lead consist and the middle consist), the middle and remote consists are grouped together and operate using the same control signals. The propulsion-generating vehicles **904**C, **904**D may then use the same throttle notch settings as each other, while the propulsion-generating vehicles **904**A, **904**B can use the same throttle notch settings as each other. But, the throttle notch settings of the propulsion-generating vehicles **904**C, **904**D may be different from the throttle notch settings of the propulsion-generating vehicles **904**A, **904**B. When the fence is located at a middle-remote position (e.g., between the middle consist and the remote consist), the lead and middle consists are grouped together and operate at the same control signals. As a result, the propulsion-generating vehicles **904**A-C can then use the same throttle notch settings as each other, while the propulsion-generating vehicle **904**D can use the same or a different throttle notch setting.

A trip plan for the vehicle system can be created to designate operational settings of the propulsion-generating vehicles as a function of time and/or distance along the route. For example, the trip plan can designate speeds of the vehicle system as a function of one or more of time and/or distance along the route. This trip plan may include or be associated with command profiles that designate operational settings of the propulsion-generating vehicles. For example, the command profiles can dictate the throttle notch positions or other settings of the propulsion-generating vehicles as a function of time and/or distance along the route. The trip plan may include or be associated with change indices that dictate locations of the vehicle system along the route and/or times at which the groups in which the propulsion-generating vehicles are included changes. Optionally, the trip plan may include or be associated with change indices that dictate positions of the fence in the vehicle system at different locations along the route and/or times at which the position of the fence is to change.

The command profiles and/or change indices may be created by considering parameters of the vehicle system, such as in-system forces (e.g., coupler forces, or the like) or other parameters described above. Controlling these parameters (e.g., keeping the parameters within designated limits) contributes to safe running of the vehicle system and to limiting maintenance cost. For example, the larger the in-system forces are, the more likely it is that couplers between the vehicles frequently experience fatigue. The fatigue has a large impact of the life of a coupler, and the break of a coupler will cause safety concerns and increased cost of maintenance.

The command profiles and change indices may be created by modeling the vehicle system as a "rope model," which considers the vehicle system as a cascade of connected mass points, with each connection between vehicles being modeled as a rigid connection without any dynamic action of the connection. This model is based on information about the make-up of the vehicle system and the positions of the vehicles in the vehicle system, so that the model can be used to estimate the parameters. Optionally, another model may be used, such as a lumped mass model, a dynamic model, or another model.

By changing which vehicles are included in the different groups and/or moving the fence during the trip, the parameters are further addressed with the freedom to change the group assignments of the vehicles. The parameters are expected to improve relative to not changing which vehicles are included in which groups and/or relative to not moving the fence, especially in terrain where the grade changes. For example, when the vehicle system is crossing a hill, the groups of the vehicles can change and/or the fence can be moved to dictate which vehicles use the same settings so that, after the lead consist passes the top of the hill, the lead consist can begin braking and motoring may be applied in the remote consist. After the middle consist passes the top of the hill, a braking signal can be applied to the middle consist while still providing a motoring signal to the remote consist.

FIG. **10** illustrates a flowchart of a method **1000** for determining command profiles and/or change indices that dynamically change group assignments of the vehicles and/or fence positions in the vehicle systems shown herein according to one embodiment. The method **1000** can be used to generate command profiles and/or change indices for use in controlling operations of the vehicle system.

At **1002**, data used to determine command profiles are obtained. This data can include system data, which represents characteristics of the vehicle system. For example, the system data can include a size of the vehicle system (e.g., length, mass, weight, etc.), an arrangement or locations of the propulsion-generating vehicles and/or non-propulsion-generating vehicles in the vehicle system (e.g., where the vehicles are located in the vehicle system), or the like. The data that is obtained may include vehicle data, which represents characteristics of the vehicles. For example, the vehicle data can include the horsepower (HP) that the vehicles can produce, the braking efforts that the vehicles can produce, and the like. The data that is obtained may include route data, such as the layout of the route that is to be traveled upon. The layout of the route can include grades, curvatures, and the like, of the route.

The data that is obtained can include constraint data, such as information representative of limitations on how the vehicle system is controlled. These limitations can include restrictions on how often or frequently the group assignments of the vehicles are changed, how often of frequently the fence is moved within the vehicle system, limitations on how many throttle notch positions and/or brake settings the vehicles can use, limitations on how large of a change between notch positions or settings and/or brake settings can be used, limitations on how many fences can be used to assign the vehicles to different groups, or the like.

For example, the notch setting represents the tractive effort that each vehicle **104** can produce. In rail vehicles, the notch setting may extend from −8 to 8, where −8 represents maximum braking effort and 8 represent the maximum motoring effort. These notch settings may be limited to values of −8 to 8. Also, the notch command, or control sign, may not be allowed to change simultaneously. The notch command may be permitted to only change a single notch (e.g., from −8 to −7) in a designated time period (e.g., three seconds). Other data that may be obtained can include a trip plan that designates operational settings of the vehicle system as a function of time and/or distance along the route. As described herein, this trip plan can dictate speeds or other settings of the vehicle system as a function of time and/or distance.

Additional constraints can include fuel consumption limits, where certain operational settings are not permitted for one or more propulsion-generating vehicles as these settings could cause the vehicles to consume more fuel or to consume fuel at a greater rate than desired. For example, a propulsion-generating vehicle may not be permitted to be assigned a notch setting that would cause the vehicle to consume more fuel than the vehicle is carrying and/or consume fuel at a such a rate that the vehicle will not have sufficient fuel to complete a trip.

Another operating constraint can include engine derating. One or more engines of the propulsion-generating vehicles may be derated and unable to generate the horsepower or tractive effort associated with the rating of the engines. The decreased output or capability of these engines may be used to limit what operational settings are assigned to different vehicles to prevent the vehicles from having to operate the engines at levels that exceed the derated capabilities of the engines.

Another example of an operating constraint can include a notch delta penalty. Such a penalty can restrict how much and/or how quickly an operational setting of a vehicle is allowed to change. For example, a notch delta penalty may not allow the throttle notch setting for a propulsion-generating vehicle to change by more than three positions (e.g., throttle notch one to throttle notch four). Instead, the vehicle may be limited to changing throttle positions by three positions or less at a time.

Another example of an operating constraint can be a limitation on how frequently a position of a virtual fence is changed. For example, such a constraint may not permit a location of a fence in the vehicle system **100** to change more frequently than a designated frequency or time period.

Another example of an operating constraint can be a limitation on a number of fences that can be included in the vehicle system. For example, different locations or segments of the route being traveled upon or that are to be traveled upon may have restrictions on the number of groups to which the vehicles can be assigned. Segments of the route having undulations, curves, or the like, may be restricted to fewer fences or vehicle groups than segments of the route having fewer undulations, curves, or the like.

At **1004**, parameters are determined for different groups of the vehicles and/or different fence positions. In one embodiment, a rope model can be used to estimate the expected forces exerted on couplers between the vehicles in the vehicle system when the vehicles are associated with different vehicle group assignments and/or the fence is at different positions at one or more locations along the route. The rope model can assume that the vehicle system includes mass points (which represent the vehicles) connected with connections, such as couplers, spacings between aerodynamically and/or fluidly coupled vehicles, or the like. The connection may be assumed to be rigid without dynamic movements.

The parameters can be determined based on at least some of the data obtained at **1002**. As one example, the parameters can be based on a trip plan for the vehicle system. The trip plan can designate operational settings of the vehicle system as a function of time and/or distance along the route. For example, the trip plan can dictate speeds at which the vehicle system is to travel at different times and/or locations along the route. Optionally, the trip plan can dictate other settings of the vehicle system.

As one example that is not intended to limit all embodiments of the subject matter described herein, coupler forces may be calculated as the parameters. Alternatively, one or more other parameters may be calculated, estimated, sensed, or the like. In order to estimate the coupler forces as parameters, other forces on the connected vehicles can be examined. A vehicle may be subject to internal forces from neighboring vehicles, gravity forces, aerodynamic forces, traction forces, and the like. One of these forces includes drag on a vehicle. The total drag on a moving vehicle can be expressed by the sum of aerodynamic and mechanical forces as follows:

$$f=a+bv+cv^2 \qquad \text{(Equation \#19)}$$

where f represents total drag on the vehicle, v represents the speed of the vehicle, and a, b, and c are constants determined by experiments (and usually referred to as David coefficient parameters).

Another force that may be exerted on the vehicle can include a resistance force. The resistance force can be based on the location of the vehicle along the route, and may be expressed as follows:

$$f_p = f_g + f_c \quad \text{(Equation \#20)}$$

where f_p represents the resistance force, f_g represents a gravity force, and f_c represents a curvature resistance force. The gravity force (f_g) may be expressed as follows:

$$f_g = mg \sin\theta \quad \text{(Equation \#21)}$$

where m represents the mass of the vehicle, g represents the gravitational force, and θ represents the angle at which the vehicle is tilting or moving. The curvature resistance force (f_c) represents the force exerted on the vehicle by the vehicle moving along a curved section of the route. Because the layout of the route may be known, this curvature resistance force (f_c) may be previously measured, calculated, or estimated. In one aspect, a distribution of weight or mass of the vehicles in the vehicle system may not be even. For example, the masses of the vehicles in one location or portion of the vehicle system may be larger than the masses of the vehicles in other locations or portions of the vehicle system. Alternatively, the masses of the vehicles may be even throughout the vehicle system, such as the masses of all vehicles **904**, **906** being equal or within a designated range of one another, such as within 1%, 3%, 5%, 10%, or the like.

The model of the vehicle system may be is described by one or more (or all) of the following expressions:

$$m_i \dot{v}_i = u_i + f_{i-1} - f_i - f_{a_i} - f_{p_i},\ i = 1, 2, \ldots, n \quad \text{(Equation \#22)}$$

$$\dot{x}_j = v_j - v_{j+1},\ j = 1, 2, \ldots n-1 \quad \text{(Equation \#23)}$$

where m_i represents the mass of the i^{th} vehicle in a vehicle system including n vehicles, v_i represents the speed of i^{th} vehicle, f_{a_i} represents the aerodynamic force exerted on the i^{th} vehicle, f_{p_i} represents the force exerted on the i^{th} vehicle due to the grade and curvature of the route where the i^{th} vehicle is moving, f_i represents the forces between the i^{th} and $(i+1)^{th}$ vehicles, u_i represents the force that the i^{th} vehicle generates (e.g., which may be zero for a non-propulsion generating vehicle or the tractive effort generated by a propulsion-generating vehicle). x_j represents the difference in velocities between the j^{th} vehicle and the neighboring $(j+1)^{th}$ vehicle.

One objective of the model can be to reduce in-system forces, as well as the fuel consumption and/or emission generation of the vehicle system. In one embodiment, a speed profile that is generated to reduce fuel consumption and/or emission generation may be obtained, and the in-system forces on the vehicles may be modeled using the speeds designated by such a profile. In scheduling the open loop controller, it is assumed that the desired speed is reached and held. The objective of the model can be expressed as:

$$J = \sum_{i=1}^{n} f_i^2 \quad \text{(Equation \#24)}$$

where J represents a cost function representative of in-system forces of the vehicle system and f_i represents the coupler force of the i^{th} vehicle. Different notch settings can be examined for different locations along the route in order to calculate different values of the cost function (J), subject to the constraints described above.

The cost function (J) can be used to identify the groups of the vehicles and/or the positions of the fence within the vehicle system at different locations along the route and/or times of the trip. As used herein, the term "potential change point" refers to a location along the route and/or time during a trip of the vehicle system where the parameters are determined, or the groups of vehicles and/or fence positions may change. The potential change points of a trip may represent designated, periodic locations, such as every kilometer, every few kilometers, very few fractions of a kilometer, or other distance, along a route. Optionally, the potential change points can represent designated, periodic times, such as every second, minute, hour, or the like. In one aspect, the potential change points may be defined by an operator, and/or may not be periodic in location.

The vehicle group assignments and/or fence positions may not change at every potential change point. The vehicle system may travel through several potential change points without changing the vehicle group assignments or fence positions. As used herein, the phrase "potential change point along the route" may represent a geographic location or an elapsed time during a trip. In one embodiment, group assignments of the vehicles and/or a position of a fence are chosen where the cost function (J) has a minimum value among all possible group assignments of the vehicles and/or positions of the fence at a location along the route, or where the cost function (J) has a lower value than one or more other group assignments of the vehicles and/or positions of the fence at the potential change points along the route. This can be described as a control problem that is expressed as follows:

$$\min_s J(s) = \min_s \sum_{i=1}^{n} f_i^2(s) \quad \text{(Equation \#25)}$$
$$= 1, 2, \ldots, v$$

where s represents possible positions of the fence, which also can dictate which vehicles are in which groups. For example, the vehicles between two fences, between a fence and a leading end of the vehicle system, or the vehicles between a fence and a trailing end of the vehicle system may be included in a group. As a result, the position of the fence in the vehicle system and/or the group assignments of the vehicles at different potential change points of the vehicle system along the route can be determined based on the in-system forces, as described above.

In one embodiment, the parameters that are calculated may be normalized and/or bunching power (e.g., horsepower) metrics may be calculated. With respect to normalizing the in-system forces (e.g., the coupler forces), these calculated forces may be normalized by multiplying or dividing the forces by a factor. In one embodiment, these forces may be normalized using the following expression:

$$J_{force}(k, i) = \frac{J_{IDP}(k, i) - \min_i(J_{IDP}(k, i))}{thresh} \quad \text{(Equation \#26)}$$

where $J_{force}(k, i)$ represents a normalized value of an in-system force (e.g., a coupler force) that is calculated as being exerted on a coupler at position of the fence that is at the i^{th} vehicle at a potential change point along the route defined by the k^{th} potential change point, $J_{IDP}(k, i)$ represents a combination of the calculated in-system forces, thresh represents a designated constant value, and $\min_i(J_{IDP}(k, i))$ represents a minimum value of the in-system forces calculated for all positions of the fence or all group assignments of the vehicles at all potential change points. The k potential change points along the route can represent designated potential change points along the route or during the trip. These potential change points optionally can be referred to as "mesh points." Alternatively, $\min_i(J_{IDP}(k, i))$ can represent a value of the in-system forces that is less than one or more, but not all, of the in-system forces calculated for possible positions of the fence and/or all group assignments of the vehicles at possible potential change points. In one aspect, $J_{IDP}(k, i)$ can represent a sum of squared coupler forces that are calculated for a position of the fence that is at the i^{th} vehicle at a potential change point along the route defined by the k^{th} potential change point. Optionally, $J_{IDP}(k, i)$ can represent another combination of these forces. In another embodiment, the in-system forces can be normalized in another manner, such as by dividing the calculated forces by a maximum calculated force, a minimum calculated force, a designated value, another calculated force, or the like.

Optionally, bunching power metrics can be calculated. The bunching power metrics can represent the amount of tractive effort or power that is calculated as being generated by different groups of the propulsion-generating vehicles at different positions of the fence at the different potential change points. In one embodiment, the bunching power metrics can be calculated using the following expression:

$$J_{bunch}(k, i) = \frac{HP_{bunching}(k, i)}{\max(\text{abs}(THP))} \quad \text{(Equation \#27)}$$

where $J_{bunch}(k, i)$ represents the bunching power metric for the vehicle system **100** when the fence **112** is at a position at the i^{th} vehicle and the vehicle system **100** is at the k^{th} potential change point, $HP_{bunch}(k, i)$ represents the differential combined power output (e.g., the difference in power on opposite sides of the fence) generated by the propulsion-generating vehicles when the fence is at a position at the i^{th} vehicle and the vehicle system is at the k^{th} potential change point, and max(abs(THP)) represents the maximum value of the total power (e.g., horsepower) that can be generated by the propulsion-generating vehicles in the vehicle system. Optionally, max(abs(THP)) can represent another value that is not the maximum value of the total power (e.g., horsepower) that can be generated by the propulsion-generating vehicles in the vehicle system.

Alternatively, the parameters may be determined in another manner. As described above, the parameters optionally can include coupler parameters, terrain excitation parameters, node parameters, neighboring velocity parameters, or based on natural forces. In one aspect, the parameters may be determined without having grade information about the route being traveled upon or that is to be traveled upon. In such a situation, the parameters can be determined by measuring forces exerted on the couplers (e.g., using a force sensor connected with a coupler or to the vehicles connected by the coupler), by measuring separation distances between neighboring vehicles (e.g., with decreasing separation distances indicating that a coupler between the vehicles may be transitioning from a tension or slack state to a compressed state and with increasing separation distances indicating that a coupler between the vehicles may be transitioning from a compressed or slack state to a state of tension). Optionally, the parameters can be determined based on energy differences. For example, the total energy of the vehicle system may be a combination of kinetic energy and potential energy. The potential energies of the vehicle system at various locations can be estimated or determined, such as based on the altitude at which the vehicle system is located as obtained from a global positioning system (GPS) receiver. The kinetic energy can be estimated or determined based on the speed at which the vehicle system is moving. The combined kinetic and potential energies can be determined for different vehicles in the vehicle system. If the combined kinetic and potential energies at one or more vehicles changes over time, then the differences between the total energies of the vehicle system can indicate changing energies stored in or exerted upon couplers connected to the vehicle(s) as forces. These changing energies or coupler forces can be used as the parameters for the various vehicles.

With the parameters (e.g., coupler forces) being calculated or determined for different positions of the fence at different potential change points along the route at **1004**, the method **1000** can proceed to **1006**. At **1006**, a value of a variable k is set to 1. This variable k can have different values to represent different potential change points along the route. For example, if the route includes 100 different potential change points (e.g., mesh points), then the variable k can change in value from one to 100. Alternatively, this variable can have other values. The method **1000** can proceed by changing the values of k to examine the calculated in-system forces and/or bunching power metrics at different potential change points along the route. As described below, the method **1000** may determine to change or move a position of the fence (or otherwise change which vehicles are assigned to which groups) at one or more of these potential change points as the method **1000** examines the parameters.

At **1008**, a determination is made as to whether the vehicles in one or more of the groups and/or the position of one or more fences was last changed within a designated period of time. For example, the method **1000** can examine previous potential change points and the times at which the vehicle system is expected to travel through these potential change points (e.g., using a designated speed of a previously determined trip plan or speed profile) to determine if the group assignments of the vehicles and/or the position of one or more fences in the vehicle system changed in less than a threshold dwell time period ago. If the vehicle group assignments and/or fence position was changed relatively recently (e.g., in less than the threshold dwell time period), then the group assignments may remain the same and/or the position of the one or more fences may not be moved again to avoid changing the group assignments and/or fence positions too quickly.

For example, the dwell time period may be set to one minute to ensure that the vehicle group assignments and/or fence positions do not change more than once per minute. Alternatively, another dwell time period may be used. If the vehicle group assignments and/or fence positions changed recently within this dwell time period, then flow of the method **1000** can proceed to **1010**. On the other hand, if it has been a longer than the threshold dwell time period since the vehicle group assignments and/or fence positions were last changed, then the vehicle group assignments and/or fence positions may be able to be changed again. As a result, flow of the method **1000** can proceed to **1012**.

At **1010**, the vehicle group assignments and/or fence positions are not changed when the vehicle system **1000** is at the k^{th} potential change point along the route. For example, the method **1000** may have determined to change the vehicle group assignments and/or fence positions too recently to safely allow for the vehicle group assignments and/or fence positions to be changed again at the k^{th} potential change point. Flow of the method **1000** can proceed from **1010** toward **1016**, as described below.

At **1012**, a determination is made as to whether there is at least a threshold benefit to changing the vehicle group assignments (e.g., by moving the fence positions) when the vehicle system is at the k^{th} potential change point along the route. The parameters that are calculated, estimated, or sensed can be examined in order to determine if changing the vehicle group assignments at the k^{th} potential change point results in an improvement in the vehicle parameters that is at least as large as the threshold benefit (where the threshold benefit represents a magnitude of the parameters). As one example, the coupler forces that are estimated as the parameters if the position of the fence is moved at the k^{th} potential change point and the coupler forces that are estimated as occurring during an upcoming period of time in the trip (e.g., twice the time of the threshold dwell period of time or another time period) are examined.

If changing the vehicle group assignments at the k^{th} potential change point results in the parameters improving over this upcoming period of time by at least the amount of the threshold benefit, then changing the vehicle group assignments at the k^{th} potential change point may be desirable. For example, if changing the vehicle group assignments results in a calculation of the coupling forces decreasing by at least a designated, non-zero threshold amount, then changing the vehicle group assignments occurs. Optionally, the parameters may be examined to determine if changing the vehicle group assignments results in a calculated increase of the parameters by at least a threshold benefit amount. As a result, flow of the method **1000** can proceed to **1012**.

On the other hand, if changing the vehicle group assignments at the k^{th} potential change point does not result in the parameters improving over the upcoming period of time by at least the amount of the threshold benefit, then changing the vehicle group assignments at the k^{th} potential change point may not be desirable. For example, the reduction in the coupler forces may be sufficiently small that keeping the current position of the fence may be desired over moving the fence. As a result, flow of the method **1000** can proceed to **1010**. At **1010**, the vehicle group assignments at the k^{th} potential change point may remain the same. For example, the fence can remain at the same position as the $(k-1)^{th}$ potential change point (or may not move if the value of k is one).

At **1014**, a sequence of changes in the vehicle group assignments is determined for when the vehicle system is at the k^{th} potential change point. For example, a sequence of movements of the position of the fence can be determined for when the vehicle system is at the k^{th} potential change point. The method **1000** can determine this order at **1014**.

A sequence of changes in the vehicle group assignments can be represented as different groups of the vehicles at different potential change points of the vehicle system along the route. The groups can be different at different potential change points by assigning the vehicles to different groups, without physically moving or changing the positions of the vehicles within the vehicle system. For example, a sequence may include a first group of the vehicles (e.g., the vehicles **904**A, **904**B in a first group and the vehicles **904**C, **904**D in a second group) when the vehicle system is at a first potential change point along the route; followed by a different, second group of the vehicles (e.g., the vehicle **904**A in the first group, the vehicles **904**B, **904**C in the second group, and the vehicle **904**D in a third group) when the vehicle system is at a different, second potential change point along the route; followed by a different, third group of the vehicles (e.g., the vehicles **904**A, **904**B, **904**C in the first group and the vehicle **904**D in the second group) when the vehicle system is at a different, third potential change point along the route; and so on. Optionally, the sequence of changes in the vehicle group assignments can be represented by a sequence of changes in fence positions. With respect to the preceding example, such a sequence may include a first fence between the vehicle **904**B and the vehicle **904**C when the vehicle system is at the first potential change point along the route; the first fence between the vehicle **904**A and the vehicle **904**B, and a second fence between the vehicle **904**C and the vehicle **904**D when the vehicle system is at the second potential change point along the route.

Alternatively, the groups can be different at different potential change points by physically moving one or more of the vehicles so that the positions of the vehicles changes within the vehicle system. For example, a sequence may include the vehicles **904**A, **904**B in a first group and the vehicles **904**C, **904**D in a second group when the vehicle system is at a first potential change point along the route; followed by a different grouping of the vehicles that results from switching the positions of the vehicles **904**B and **904**C such that the vehicles **904**A, **904**C are in one group and the vehicles **904**B, **904**D are in another group.

Optionally, the groups can be different at different potential change points by adding one or more vehicles to the vehicle system and/or removing one or more vehicles from the vehicle system. For example, a sequence may include the vehicles **904**A, **904**B in a first group and the vehicles **904**C, **904**D in a second group when the vehicle system is at a first potential change point along the route. At a subsequent second potential change point, a vehicle may be added to the vehicle system (e.g., a helper vehicle or helper locomotive) and assigned to a group that includes one or more of the vehicles **904**. At another, third potential change point, the vehicle that was added at the second potential change point may be removed from the vehicle system and/or another vehicle may be added to the vehicle system. At another, fourth potential change point, one or more of the vehicles **904** may be removed from the vehicle system.

In one embodiment, the assignments of the vehicles to different groups can change at different potential change points by separating the vehicle system into two or more smaller vehicle systems. Due to a segment of the route having several undulations and/or curves (or another reason), the parameters of the vehicle system may be improved by separating the vehicle system into two or more separate vehicle systems that travel over the segment of the route as separate, non-connected vehicle systems and then combine back together to form the original vehicle system after traveling over the segment of the route. The parameters may be improved when separating the vehicle system into smaller vehicle systems relative to the larger vehicle system traveling over the segment of the route without dividing the vehicle system into the smaller vehicle systems. As one example, prior to reaching a first potential change point, the vehicle system **900** may travel with the vehicles **904**A-D and **906**A-F being mechanically interconnected with each other such that the vehicle system **900** moves as a unit. Upon reaching the first potential change point, it may be determined that the parameters of the vehicle system **900** can be improved by separating the vehicles **904**A, **904**B, **906**A, and **906**B from the vehicles **904**C, **906**C, **906**D, **906**E, **906**F, and **904**D such that two smaller vehicle systems are formed. The first smaller vehicle system can be formed by the vehicles **904**A, **904**B, **906**A, and **906**B and the second smaller vehicle system can be formed by the vehicles **904**C, **906**C, **906**D, **906**E, **906**F, and **904**D. Alternatively, three or more smaller vehicle systems can be formed. The separate, smaller vehicle systems can travel along the route to a subsequent potential change point, where it may be determined that the parameters of the smaller vehicle systems can be improved by re-combining the smaller vehicle systems into the larger vehicle system **900** (and/or assigning the vehicles **904** to different groups). The smaller vehicle systems may then be re-combined into the larger vehicle system **900**.

In one embodiment, the method **1000** can employ an "exhaustive search" technique to identify the sequence of changes to the vehicle group assignments. This technique can involve estimating the vehicle parameters (e.g., coupler forces or other parameters) for all different permutations of the possible sequences of changes in the vehicle group assignments (e.g., changes in the positions of the fence) during an upcoming designated period of time (e.g., twice the threshold dwell time period or another time period). The sequence of changes in the vehicle group assignments that results in estimated parameters improving (e.g., decreasing or increasing, as appropriate) by the most or more than one or more other sequences may be identified as a selected sequence. For example, the sequence of changes in the fence positions that results in the estimated coupler forces being less than all other sequences or that are less than at least a designated number of other sequences may be identified as the selected sequence.

In another embodiment, the method **1000** can employ a "dynamic programming" technique to identify the selected sequence of changes to the vehicle group assignments. This technique can involve estimating the parameters for many, but less than all, different permutations of the possible sequences of changes in the group assignments of the vehicles during the upcoming designated period of time. In contrast to the "exhaustive search" technique, the "dynamic programming" technique may not examine certain designated sequences of changes in the vehicle group assignments. The "dynamic programming" technique may exclude certain sequences of changes from consideration that are previously identified as undesirable or non-optimal sequences of changes. These sequences may be identified by an operator of a system that performs the method **1000**, may be identified by previous generations of command profiles for the vehicle system, or may be identified in another manner. Among the sequences that are examined in the "dynamic programming" technique, the sequence of changes in the vehicle group assignments that results in estimated parameters that are less or larger than other sequences (as appropriate) or that are less than or greater than (as appropriate) at least a designated number of other sequences may be identified as the selected sequence. Some of the sequences that may not be examined may include those sequences that result in changes in fence positions that occur more frequently than a designated limit or exceed the fence restrictions, changes in operational settings of one or more vehicles that are larger than one or more designated limits, changes in the fence positions and/or operational settings that previously were identified as causing an undesired change in parameters, or the like.

In another embodiment, the method **1000** can employ a "complete trip dynamic programming" technique to identify the selected sequence of changes to the vehicle group assignments. This technique can involve estimating the parameters for many, but less than all, different permutations of the possible sequences of changes in the vehicle group assignments during a period of time that is longer than the upcoming designated period of time. For example, this technique can apply the "dynamic programming" technique described above to the entire trip of the vehicle system or to another period of time that is longer than the upcoming designated period of time.

In another embodiment, the method **1000** can employ a "hybrid" technique to identify the selected sequence of changes to the vehicle group assignments. This technique can involve examining the parameters for different vehicle group assignments (e.g., at different fence positions) at different potential change points along the route and selecting the sequence that reduces or minimizes (or increases or maximizes, as appropriate) the parameters over a designated period of time (e.g., the threshold dwell time period) following a change in the vehicle group assignments.

With continued reference to the method **1000** shown in FIG. **10**, FIG. **11** illustrates a table **1100** demonstrating possible sequences of changing the vehicle group assignments in the vehicle system according to one embodiment. The parameters estimated from changing the vehicle group assignments according to the different sequences may be used to determine the selected sequence. The table **1100** includes several potential change point columns **1102** representative of different upcoming potential change points along the route. The table **1100** also includes several sequence rows **1104** representative of different sequences of changing the vehicle group assignments in the vehicle system. In each of the sequence rows **1104**, one or more "X" symbols are shown. The location of the X symbols indicates the potential change point or potential change points in the corresponding sequence at which the vehicle group assignments are changed in that sequence when the vehicle system arrives at or passes through the potential change points. For example, the first sequence can include changing the position of the fence at the k^{th} and $(k+4)^{th}$ potential change points, the fifth sequence can include changing the position of the fence at the $(k+1)^{th}$ and $(k+5)^{th}$ potential change points, and so on.

Several movement ban boxes **1106** are overlaid on the table **1100**. These boxes **1106** represent the time periods over which the vehicle group assignments are not allowed to change following a previous change in the vehicle group assignments. For example, these boxes **1106** can correspond to the dwell time period over which the fence positions do not change following a preceding change in the fence positions. With respect to the third sequence, the box **1106** begins at the k^{th} potential change point along the route (the potential change point of the vehicle system along the route where the vehicle group assignments are changed, such as by changing the position of the fence) and extends to the $(k+3)^{th}$ potential change point along the route to indicate that the vehicle group assignments cannot be moved again until at least the $(k+^{4})^{th}$ potential change point along the route. Other sequences include similar boxes **1106**. With respect to the boxes **1106** in the latter potential change points, the length of the boxes **1106** is reduced in FIG. **11** due to size constraints of the table **1100**. But, these boxes **1106** would extend to additional potential change points not shown in the table **1100**.

The "hybrid" technique of identifying the selected sequence of changes to the vehicle group assignments (e.g., sequence of movements of the fence) can determine which of the sequences improves the parameters (e.g., by reducing the in-train forces) while optionally penalizing changes in the vehicle group assignments and/or penalizing bunching horsepower in the vehicle system. In one embodiment, the estimated parameters for a sequence of changes to the vehicle group assignments may be expressed as follows:

$$J = J1 + \frac{J2}{A} + J3 * movePenalty + J4 * bunchPenalty \quad \text{(Equation \#28)}$$

where J represents the estimated parameters for a sequence (e.g., the coupler forces or other parameters), **J1** represents a maximum value of $J_{force}(k, i)$ calculated for the different potential change points of the vehicle system along the route and different group assignments of the vehicles (e.g., different fence positions, as described above), **J2** represents a mean value of the values of $J_{force}(k, i)$ calculated for the different potential change points and different group assignments of the vehicles (e.g., different fence positions), **J3** represents a sum of the absolute values of changes in positions of the fence (e.g., which correspond or are determined from the changes in group assignments of the vehicles), and **J4** represents the maximum of the absolute values of $J_{bunch}(k, i)$ for the vehicle system before and after each change in vehicle group assignments. Optionally, **J1** may represent a value of $J_{force}(k, i)$ that is larger than one or more other values of $J_{force}(k, i)$, but not necessarily the maximum value. Alternatively, **J2** can represent a median or other value of $J_{force}(k, i)$ calculated for the different potential change points along the route and different vehicle group assignments. With respect to **J3**, this variable can be calculated by determining how far (e.g., in terms of number of potential change points, number of vehicles, distance along the length of the vehicle system, or otherwise) that one or more fences are moved between changes in the vehicle group assignments. For example, if a change in vehicle group assignments would correspond to moving a fence by a designated distance, then this designated distance can be used to calculate **J3**. **J3** can represent a combination of how far the fence is being moved within a sequence being examined. Optionally, **J4** can represent a value of $J_{bunch}(k, i)$ for the vehicle system before and after each change in the vehicle group assignments that is larger than one or more other values of $J_{bunch}(k, i)$, but that is not necessarily the largest value. The movePenalty and bunchPenalty variables may have designated values that are based on how large the values of $J_{force}(k, i)$ are for a sequence. For example, for larger values of $J_{force}(k, I)$, such as normalized values that exceed one, the value of the movePenalty and/or bunchPenalty decreases (such as to one or zero). For smaller values of $J_{force}(k, i)$, such as normalized values that are one or less, movePenalty and/or bunchPenalty may have increased greater than one.

The value of J can be calculated for each sequence, or at least plural different sequences. The values of J can be compared to determine which sequence yields a value of J that is less than all other sequences, or that is less than one or more other sequences, but not necessarily all sequences. The sequence having the lower or lowest value of J can be identified as the selected sequence. If the values of J for the sequences are less than one, then the vehicle group assignments and/or the fence positions may not be changed for the k^{th} potential change point along the route.

The selected sequence may then be used to determine when and/or where along the route to change the vehicle group assignments. For example, if the eighth sequence in the table **1100** is identified as the selected sequence, then the vehicle group assignments or position of the fence may change when the vehicle system reaches the $(k+2)^{th}$ potential change point and again when the vehicle system reaches the $(k+6)^{th}$ potential change point (as indicated by the "X's" in the table **1100**).

Optionally, the selected sequence can be used to determine a makeup of the vehicle system. For example, different selected sequences can be determined for different vehicle systems, with the different vehicle systems having different propulsion-generating vehicles **904** (e.g., different numbers of the vehicles **904**, different types of the vehicles **904**, etc.), different non-propulsion-generating vehicles **906** (e.g., different numbers of the vehicles **906**, different types of the vehicles **906**, different cargo being carried by the vehicles **906**, etc.). The locations, numbers, types, or the like, of the vehicles **904**, **906** in a vehicle system can be referred to as a vehicle arrangement or make-up of the vehicle system. Different sequences may be determined for two or more different vehicle arrangements. Depending on which sequences have the best or better parameters than one or more other sequences, the vehicle arrangement associated with the sequence or sequences having the better parameters may be used to form the vehicle system.

Returning to the description of the flowchart of the method **1000** shown in FIG. **10**, at **1016**, a determination is made as to whether the current value of k is equal to the total number of potential change points in the trip. For example, a determination may be made as to whether a sequence for changing vehicle group assignments or fence positions has been selected for all of the designated potential change points (or at least a designated amount of the designated potential change points) along the route. If a sequence has been selected for the designated potential change points, then flow of the method **1000** can proceed to **1020**. Otherwise, additional potential change points along the route may need to be examined to determine whether to change vehicle group assignments and/or fence positions, and/or to determine the sequence to use in changing the vehicle group assignments and/or fence positions. As a result, flow of the method **1000** can proceed toward **1018**.

At **1018**, the value of k is increased by one. For example, the value of k may be changed and flow of the method **1000** can return to **1008** so that the determination of whether to change vehicle group assignments and/or fence positions, and/or the identification of the sequence in which to change the vehicle group assignments and/or fence positions can be performed for another potential change point along the route.

At **1020**, command profiles and/or change indices are generated using the selected sequences. The command profiles can include operational settings for inclusion in and/or use with a trip plan. The operational settings can indicate which throttle notch positions are to be used for which propulsion-generating vehicles and/or groups of the propulsion-generating vehicles at various locations along the route (e.g., at potential change points and/or other locations along the route), the brake settings of the vehicles **904** and/or **906**, the speeds of the vehicles **904** and/or **906**, or the like.

The change indices can include position indices and/or time indices. The position indices can indicate the potential change points along the route at which the operational settings are to be used. The operational settings may be designated so that one or more groups of the vehicles have the same operational settings at the same potential change points. As a result, the operational settings and the corresponding potential change points designated by the command profile can arrange the vehicles into groups and/or establish virtual fences between different groups of the vehicles, as described above. Because the operational settings and assignments of the vehicles to different groups may not change at every single potential change point along the route for a trip, the number of position indices in a plan may be smaller than the number of potential change points along the route for the trip.

The time indices can indicate the times during travel of the vehicle system along the route at which the corresponding operational settings are to be used. The operational settings may be designated so that one or more groups of the vehicles have the same operational settings at the same times. As a result, the operational settings and the corresponding times designated by the command profile can arrange the vehicles into groups and/or establish virtual fences between different groups of the vehicles, as described above. In one aspect, the position indices may be used in place of the time indices, or the time indices may be used in place of the position indices. Alternatively, both the position indices and the time indices may be used.

The command profiles, position indices, time indices, and/or trip plan can then be communicated to the vehicle system in order to direct an onboard operator how to control the propulsion-generating vehicles, to automatically control the propulsion-generating vehicles, or the like. The vehicle system may then travel on the route for the trip using the operational settings, position indices, and/or time indices to change vehicle group assignments and/or fence positions during the trip.

In another embodiment, the selected sequences may be determined by grouping different potential change points along the route having the same vehicle group assignments and/or fence positions together. With continued reference to the flowchart of the method **1000** shown in FIG. **10**, FIG. **12** illustrates examples of parameters (e.g., $J_{force}(k, i)$) calculated for three different vehicle group assignments or fence positions according to one embodiment. The values of the parameters are represented by parameter curves **1200**, **1202**, **1204** that are shown alongside a horizontal axis **1206** and a vertical axis **1208**. The horizontal axis **1206** represents different potential change points along the route and the vertical axis **1208** represents different values of the parameter. The parameter curve **1200** represents values of the parameter with a first vehicle group or first fence position (e.g., where the fence is located between the consist **910**A and the consist **910**B). The parameter curve **1202** represents values of the parameter with a different, second vehicle group or a different, second fence position (e.g., where the fence is located between the consist **910**B and the consist **910**C). The parameter curve **1204** represents values of the parameter with a different, third vehicle group or a third position of the fence (e.g., the fence located behind the consist **910**C or between the consist **910**C and the trailing end of the vehicle system). "X" symbols are shown along the parameter curves **1200**, **1202**, **1204** to represent the calculated values of the parameters at the different potential change points along the route for the different vehicle group assignments and/or fence positions.

With the values of the parameter calculated for the different vehicle group assignments and/or fence positions at the different potential change points along the route, a determination is made as to whether segments of potential change points along the route having the same vehicle group assignments or fence positions exist, or if segments of potential change points along the route having values of the parameters (e.g., normalized values) that are less than a designated threshold value **1216** (e.g., one or another value) exist.

In the illustrated example, first, second, and third segments **1210**, **1212**, **1214** are identified based on the values of the parameters. The first segment **1210** can be identified based on the values of parameters in the third parameter curve **1204** exceeding the threshold value **1216** across consecutive potential change points along the route (e.g., potential change points k, (k+1), and (k+2)). The third segment **1214** can be identified based on the values of the parameters in the first parameter curve **1200** exceeding the threshold value **1216** across consecutive potential change points along the route (e.g., potential change points (k+5), (k+6), (k+7)). The second segment **1212** can be identified based on the values of the parameters being less than the threshold value **1216** in consecutive potential change points (e.g., mesh points (k+3), (k+4)).

In one embodiment, the identified segments **1210**, **1212**, **1214** are examined to determine if the segments **1210**, **1212**, **1214** are sufficiently long. For example, the number of consecutive potential change points in a segment may be compared to a threshold of consecutive potential change points, such as three or another value. If the number of consecutive potential change points in a segment does not meet or exceed this threshold value, then the segment may be merged into another, neighboring segment. If the number of consecutive potential change points in a segment does meet or exceed the threshold value, then the segment may be used to create the selected sequence of changes to the vehicle group assignments and/or changes to the fence positions. This comparison to a threshold value can be used to ensure that the vehicle group assignments and/or fence positions are not changed too frequently.

With respect to the potential change points along the route at which the values of the handing parameters do not exceed the threshold value **1216** and/or the consecutive potential change points that are insufficiently long to define a separate segment (as described above), these potential change points may be merged into one or more neighboring segments. The segment of these potential change points may be referred to as a "To Be Determined" or "TBD" segment. In the example shown in FIG. **12**, the segment **1212** may be a TBD segment because the values of the parameters are less than the threshold value **1216** and/or because the number of potential change points along the route in the segment **1212** does not meet or exceed the threshold of consecutive potential change points.

In order to determine which neighboring segment **1210**, **1214** of the TBD segment **1212** to merge the TBD segment **1212** into, a determination is made as to whether the neighboring segments **1210**, **1214** on opposite sides of the TBD segment **1212** are associated with the same vehicle group assignments and/or fence positions. In the illustrated example, the segment **1210** is associated with the propulsion-generating vehicles **904**A, **904**B, **904**C, **904**D being in the same group (e.g., or the third position of the fence, which is behind the trailing consist **910**C) while the segment **1214** is associated with the propulsion-generating vehicles **904**A, **904**B being in one group and the propulsion-generating vehicles **904**C, **904**D being in another group (e.g., or the first position of the fence, which is between the leading consist **910**A and the middle consist **910**B). Therefore, the neighboring segments **1210**, **1214** of the TBD segment **1212** have different vehicle groupings and/or fence positions. As a result, the TBD segment **1212** is not merged into the segment **1210** or the segment **1214**. If, on the other hand, the segments **1210**, **1214** were associated with the same vehicle group assignments and/or fence positions as the TBD segment **1212**, then the TBD segment **1212** could be merged into the segment **1210** and/or the segment **1214** to produce a larger segment comprised of the segments **1210**, **1212**, and/or **1214**.

If the neighboring segments of a TBD segment are not associated with the same vehicle group assignments or fence positions (as is the case in the example shown in FIG. **12**), then a determination is made as to whether several TBD segments have been identified. If several TBD segments have been identified, then the TBD segments can be sorted in an order, such as longest to shortest in length (in terms of consecutive potential change points in the various TBD segments, distance along the route encompassed by the consecutive potential change points, or the like). The TBD segments can then be examined for merging into other segments in order from the longer TBD segments to the shorter TBD segments. Alternatively, the TBD segments may be examined in another order.

For a TBD segment being examined for merger into a neighboring segment, the number of consecutive potential change points in the segments that neighbor the TBD segment is examined. For example, if one of these neighboring segments has a number of consecutive potential change points that is less than the threshold number of potential change points, but that would have a number of consecutive potential change points that is at least as large as this threshold number, then the TBD segment is merged into this neighboring segment. For example, if the threshold number of potential change points is three and the segment **1214** only had two potential change points (instead of the three potential change points shown in FIG. **12**), then the TBD segment **1212** could be merged into the segment **1214** so that the merged segment would include five consecutive potential change points. Otherwise, the TBD segment is left without merging the TBD segment into any neighboring segment.

The remaining segments, which may include segments having values of the parameters that exceed the threshold value **1216**, merged segments, and TBD segments that are not merged with other segments, are then used to create the selected sequence of changes to the vehicle group assignments and/or fence positions. At the potential change points of the trip that are included in the segments having values of the parameters that exceed the threshold value **1216**, the vehicle group assignments and/or fence positions at those potential change points along the route can be the vehicle group assignments and/or fence positions associated with the values of the parameters that exceed the threshold value **1216**.

For example, the vehicle group assignments and fence positions at the potential change points k, (k+1), and (k+2) in the first segment **1210** includes the vehicles **904**A, **904**B, **904**C, and **904**D in the same group (e.g., with the fence **912** in the third position between the trailing consist **910**C and the trailing end of the vehicle system) due to the values of the parameters in the parameter curve **1204** being relatively large. The vehicle group assignments and fence position at the potential change points (k+3) and (k+4) in the TBD segment **1212** can remain at the same as the potential change points k, (k+1), and (k+2) from the first segment due to the TBD segment **1212** remaining separate from and not merged into other neighboring segments. For example, as described above, when the in-system forces are relatively low (e.g., for values of $J_{force}(k, i)$ that do not exceed the threshold value **1216**), the vehicle group assignments and/or fence positions may remain the same and not change due to the benefit of changing the vehicle groups and/or fence positions being relatively small. The vehicle group assignments and/or fence positions may then change to the vehicles **904**A, **904**B being in one group and the vehicles **904**C, **904**D being in another group (e.g., with the fence **912** between the leading and middle consists **910**A, **910**B) at the (k+5) potential change point along the route. The vehicle group assignments and fence position may remain the same at least through the (k+6) and (k+7) potential change points due to the values of the handing parameters in the parameter curve **1200** being relatively large (e.g., greater than the threshold). The sequence in which the vehicle group assignments and/or fence positions change between these segments can define the selected sequence. The command profiles, position indices, and/or time indices of the vehicle group assignments and/or fence positions can then be generated using the selected sequence, similar to as described above.

While the foregoing description focuses on changing vehicle group assignments and/or fence positions within a vehicle system having a constant number and/or arrangement of vehicles **904**, **906**, optionally, the vehicle group assignments and/or fence positions may change by adding or removing one or more vehicles. For example, a selected sequence may include adding a propulsion-generating vehicle **904** to the vehicle system (e.g., a helper locomotive) to provide additional tractive effort at a selected potential change point. The vehicle group assignments and/or fence positions may change when this additional vehicle is added. As another example, a selected sequence may include removing vehicle **904** and/or **906** from the vehicle system at a selected potential change point. The vehicle groups and/or fence positions may change when this vehicle is removed.

In one embodiment, the trip plan, command profiles, change indices, and/or time indices may be determined without having the route data described herein. For example, the grades, curvatures, or the like, of the route to be traveled along for a trip may not be available or only some of this data may be available for determining fence positions, assignments of the vehicles to different groups, determining operational settings, etc. The fence positions, vehicle assignments to different groups, operational settings, etc. may be determined based on data obtained onboard the vehicles during movement along the route. For example, the grade, curvature, or the like, of the route can be determined using positional data obtained by the vehicle system or vehicles, such as by using the GPS locations of different vehicles in the vehicle system. Differences in altitude, location, or the like, between two or more vehicles in the vehicle system can be used to calculate or estimate the grade of the route, the curvature of the route, or the like. For example, if two vehicles **904**, **906** have different altitudes and are spaced apart by a designated or estimated distance within the vehicle system, then the grade of the route between these vehicles **904**, **906** may be determined or estimated. As another example, differences in geographic coordinates between two or more vehicles **904**, **906** and/or the separation distances between these vehicles **904**, **906** can be used to calculate or approximate the curvature of the route between these vehicles **904**, **906**.

FIG. **13** illustrates a schematic diagram of a planning system **1300** according to one embodiment. The planning system can be used to generate command profiles, position indices, and/or time indices for operation of the vehicle systems described herein. For example, the planning system may perform one or more operations of the methods described herein in order to determine operational settings, vehicle group assignments, fence positions, potential change points along the route where the vehicle group assignments and/or fence positions are to change, or the like.

Components of the planning system may include or represent hardware circuits or circuitry that include and/or are connected with one or more processors, such as one or more computer microprocessors. The operations of the methods described herein and the planning system can be sufficiently complex such that the operations cannot be mentally performed by an average human being or a person of ordinary skill in the art within a commercially reasonable time period. For example, the generation of command profiles, position indices, and/or time indices for trips of vehicle systems may take into account a large amount of factors, may rely on relatively complex computations, may involve examination of many permutations of different potential sequences, and the like, such that such a person cannot complete the command profiles, position indices, and/or time indices within a commercially reasonable time period to have the command profiles, position indices, and/or time indices ready for the frequent trips of vehicle systems. The hardware circuits and/or processors of the planning system may be used to significantly reduce the time needed to determine the command profiles, position indices, and/or time indices such that these command profiles, position indices, and/or time indices can be generated within commercially reasonable time periods.

The planning system may be located onboard a vehicle system, off-board a vehicle system (e.g., at a dispatch center or other location), or may have some components disposed onboard a vehicle system and other components disposed off-board the vehicle system. The planning system includes an input device **1302** that obtains data used to determine the command profiles, position indices, and/or time indices. The input device can include a communication device, such as a wireless transceiver and associated hardware circuitry, a modem, or the like, that receives system data, vehicle data, route data, constraint data, trip plans (e.g., speed profiles), or the like, from an off-board location. Optionally, the input device can include a keyboard, microphone, touchscreen, stylus, or the like, that can receive this data.

A memory device **1304** includes one or more computer readable storage media, such as computer hard drives, random access memory (RAM), dynamic RAM (DRAM), static RAM (SRAM), read only memory (ROM), mask ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically EPROM (EEPROM), non-volatile RAM (NVRAM), flash memory, magnetic tapes, optical discs, or the like. The memory device may store the data that is obtained by the input device, trip plans (e.g., speed profiles), designated potential change points along the route (e.g., potential change points), command profiles, position indices, time indices, or the like. In one embodiment, the flowchart of the methods described herein can represent one or more sets of instructions that are stored on the memory device for directing operations of the planning system. Alternatively, the memory device may have one or more other sets of instructions **1308** stored on the memory device (e.g., software) to direct operations of the planning system as described herein.

An output device **1306** generates signals that communicate information to a vehicle system, an operator of the vehicle system, or to another location. These signals may convey the command profiles, position indices, and/or time indices determined by the planning system. For example, the output device can be the same or different communication device as the input device in order to communicate this information to another location. Optionally, the output device can include a touchscreen, display device, speaker, or the like, for communicating the command profiles, position indices, or other information. The output device can communicate the command profiles, position indices, and/or other information to the vehicle system so that the vehicle system can present the command profiles, position indices, time indices, and/or other information to an operator to direct manual control of the vehicle system and/or to direct automatic control of the vehicle system.

The planning system includes one or more modeling processors **1310** that may include and/or represent hardware circuits or circuitry that include and/or are connected with one or more processors, such as one or more computer microprocessors. The modeling processor optionally may represent one or more sets of instructions stored on a computer readable medium, such as one or more software applications. The modeling processor can perform various calculations described herein. For example, the modeling processor may determine the parameters(such as coupler forces), for different locations in the vehicle system, for different vehicle group assignments, for different fence positions in the vehicle system, for different potential change points (e.g., mesh points) of the vehicle system along the route, and the like, as described above. The modeling processor can determine the bunching power metrics, such as the bunching HP metrics, for different vehicle group assignments, different fence positions and/or different potential change points of the vehicle system, as described above.

The planning system includes one or more sequencing processors **1312** that may include and/or represent hardware circuits or circuitry that include and/or are connected with one or more processors, such as one or more computer microprocessors. In one embodiment, the one or more modeling processors and the one or more sequencing processors may be embodied in the same computer processor or two or more computer processors. The sequencing processor optionally may represent one or more sets of instructions stored on a computer readable medium, such as one or more software applications. The sequencing processor can perform various operations described herein. For example, the sequencing processor can examine the parameters determined by the modeling processor, determine potential sequences for changing the vehicle group assignments and/or moving the position and/or number of the fence(s) in the vehicle system, identify a selected sequence for changing the vehicle group assignments and/or moving the fence, and the like, as described above. The sequencing processor optionally may identify the segments of potential change points along the route where the vehicle group assignments and/or fence positions are the same and/or merge these segments to identify the selected sequence, also as described above. The sequencing processor may use the selected sequence to generate the command profiles, position indices, and/or time indices that are output by the output device to the vehicle system. As described above, these command profiles and position indices can be used to control where and when the vehicle group assignments and/or fence positions are changed within the vehicle system.

In one embodiment, the planning system may determine command profiles, change indices, time indices, fence positions and/or number of fences, operational settings, or the like, based on and/or in coordination with input from an operator of the vehicle system. The operator can provide a power request to the planning system via input provided to the input device **1302**. The processors **1310** and/or **1312** can then determine assignments of the vehicles to different groups, operational settings of the vehicles in the different groups, and/or the locations and/or times where the groups and/or operational settings are to be used such that the vehicles provide at least the amount of power requested by the operator (as indicated by the power request). In one aspect, the processors **1310** and/or **1312** can determine several different sets of vehicle assignments to different groups, operational settings, locations, and/or times and present these different sets to the operator via the output device **1306**. The operator may then select one or more of the sets via the input device **1302**. The planning system may then create and/or modify a command profile and/or change indices to provide the power requested by the operator and/or the set of vehicle assignments, operational settings, locations, and/or times selected by the operator.

In one aspect, the planning system can determine number of fences and the positions of the fences at one or more locations and/or times along the route, but the operator selects the operational settings (e.g., throttle notch positions, brake settings, or the like) for the system-determined fence settings. For example, at a first potential change point, the planning system may determine that a fence should be positioned between the vehicles **904**B and **906**A. The planning system may report this fence position to the operator (e.g., via the output device **1306**). The operator may then select the operational settings to be used by the vehicles **904**A-B and the operational settings to be used by the vehicles **906**A-D and/or the vehicles **904**C-D for this fence position (e.g., via the input device **1302**). Alternatively, the operator may select operational settings for one or more of the vehicles **904**, **906** at one or more locations and/or times along the route during a trip of the vehicle system, and the planning system can determine fence positions for the vehicles at the locations and/or times.

The planning system may provide the operator with an ability to opt out or override the number of fences and/or the position of one or more fences, operational setting, or the like, that is determined by the planning system. The planning system can inform the operator of the fence positions, operational settings, or the like, via the output device **1306**. The operator may reject the system-determined fence position, operational setting, or the like, via the input device **1302**. The planning system may determine another fence position, operational setting, or the like, and/or the operator may provide an operator-selected or operator-determined fence position, operational setting, or the like.

In one embodiment, the operational settings of different groups of the propulsion-generating vehicles **104** may be determined based on characteristics of the route being traveled upon or to be traveled upon by the vehicle system. These characteristics of the route can be represented, communicated, and/or recorded as the route data described above, and can include grades of the route, curvatures of the route, the presence and/or type of moisture on the route (e.g., rain, sleet, snow, ice, etc.), and/or the presence and/or type of debris on the route (e.g., sand, leaves, foreign objects, etc.). The route can be logically divided up into different segments for purposes of determining the operational settings of the vehicles.

The different segments of a route can be determined based on different characteristics of the route. For example, for a portion of a route that traverses up and over a hill, the portion of the route having an inclined grade toward or to the apex of the hill may be a first segment of the route and the portion of the route having a grade that declines from the apex of the hill may be a different second segment of the route. As another example, a straight portion of a route may be a third segment of the route, a curved portion of the route having a first radius of curvature may be a different fourth segment of the route, and another curved portion of the route having a different, second radius of curvature may be a different fifth segment of the route. As another example, a portion of a route that is dry and free of debris may be a sixth segment of the route, another portion of the route that has condensation or precipitation (e.g., rain, sleet, snow, etc.) may be a different seventh segment of the route, and another portion of the route that has debris (e.g., sand, leaves, or other foreign objects) may be a different, eighth segment of the route. Optionally, different segments of the route may have different combinations of different grades, curvatures, and/or condensation/debris conditions.

The fences and/or operational settings of the vehicles **104** in the vehicle system may be determined based on the different segments of the route. Optionally, the fences and/or operational settings of the vehicles **104** in the vehicle system may be determined based on the different segments of the route in order to achieve or approve upon achievement of one or more operational goals of the vehicle system.

As one example, the vehicles **104** may be assigned to different groups in the vehicle system (without changing the relative locations of the vehicles **104** within the vehicle system, such as by moving a second vehicle **104** from between a first and third vehicle **104** to being between the third vehicle **104** and a fourth vehicle **104**) based on characteristics of the route in order to transfer kinetic energy from one group of the vehicles **104** to another group of the vehicles **104**.

FIG. **14** illustrates one example of a vehicle system **1400** traversing an apex **1402** in a route **1404**. The vehicle system **1400** may represent one or more of the vehicle systems described herein and the route **1404** may represent one or more of the routes described herein. The route may be divided into different segments **1406**, **1408** based on characteristics of the route. In the illustrated example, the segments are determined by the energy management unit, the handling unit, the effort determination unit, the post processing unit, the modeling processors, and/or the sequencing processors described herein. The segments may be determined using the route data and based on the grades of the route, with the segment **1406** having a grade that is inclined toward the apex and the segment **1408** having a grade that declines from the apex. Alternatively, the segments may be determined by associating the portions of the route having the same curvature, moisture condition, and/or debris condition with each other in the same segment (and in a segment that differs from segments having other or different grades, curvatures, and/or conditions).

The vehicles may include energy generation systems **1410** that generate electric energy. The energy generation systems onboard different vehicles may be conductively coupled with each other, such as by one or more conductive pathways **1412**. In one embodiment, the energy generation systems include dynamic braking systems that convert kinetic energy of a moving vehicle into regenerated electric current. Optionally, the energy generation systems can include flywheels, solar panels, or the like. The conductive pathways **1412** can include an overhead catenary, an electrified rail, a utility grid, or the like. The vehicles may be connected with the conductive pathways **1412** by coupling mechanisms **1414**, which can represent conductive shoes, pantographs, inductive coils, or the like, for transferring electric current from the energy generation systems to the pathways and/or for receiving electric current from the pathways.

In one embodiment, the vehicles are assigned to different groups based on the segments of the routes being traveled upon by the vehicles in order to transfer energy from the vehicles in one group to the vehicles in another group of the same vehicle system. For example, the vehicles moving over the uphill segment **1406** may be assigned to a first group while the vehicles moving over the downhill segment **1408** may be assigned to a different, second group in the vehicle system. The assignment of which vehicle is in which group may change as the vehicles move over the apex **1402**. For example, a vehicle may be assigned to the first group while the vehicle is moving over the uphill segment of the route, but the vehicle may be re-assigned to the second group once the vehicle traverses the apex and is moving over the downhill segment of the route.

During movement over the downhill segment of the route, the energy generation systems onboard the vehicles in the second group may generate electric current. For example, the dynamic braking systems of the vehicles in the second group may convert the kinetic energy of these vehicles into electric current. This current may be conducted, via the coupling mechanisms of these vehicles, to the conductive pathways. One or more, or all, of the vehicles in the first group may receive some or all of this current during travel up the uphill segment of the route. The vehicles in the first group can use this current from the vehicles in the second group to power one or more components of the propulsion systems of these vehicles (e.g., traction motors).

The trip plan can be generated for the vehicle system to transfer energy between vehicles in different groups of vehicles within the same vehicle system. For example, the assignment of vehicles to different groups in the same vehicle system may be made and dynamically changing so that the vehicles in one group traveling down a downhill segment of a route provide electric current (e.g., directly through wires or other conductive pathways extending within the vehicle system or indirectly through conductive pathways extending along the route or a utility grid) to the vehicles in another group traveling up an uphill segment of the same route or a different route. The operational settings in the plan for these different groups may direct the vehicles in the downhill-moving group apply dynamic brakes of these vehicles and may direct the vehicles in the uphill-moving group to use (e.g., be powered by) the current supplied from the downhill-moving group (e.g., instead of generating additional current from an onboard engine and alternator or generator set). The assignment of which vehicles are in which group may change with respect to time as different vehicles in the same vehicle system are traveling up the uphill segment or traveling down the downhill segment of the route or routes changes.

As another example, the vehicles in different (e.g., separate) vehicle systems may be assigned to groups in different, separate vehicle systems based on characteristics of the route. FIGS. **15** and **16** illustrate another example of vehicle systems traversing the apex **1402** in the route **1404** shown in FIG. **14**. FIG. **15** illustrates a first vehicle system **1500** traveling on the downhill segment **1408** of the route **1404** and FIG. **16** illustrates a different, second vehicle system **1600** traveling on the uphill segment **1406** of the route. The first vehicle system **1500** may travel over the segments of the route shown in FIGS. **15** and **16** prior to the second vehicle system **1600**. The first and second vehicle systems represent one or more of the other vehicle systems described herein.

The first and second vehicle systems may be conductively coupled with the conductive pathways described herein. For example, the first and second vehicle systems may include conductive shoes inductively or conductively coupled with an electrified rail, wire, or other conductor extending along the route. A wayside energy storage device **1502**, such as one or more batteries, capacitors, etc., may be conductively or inductively coupled with the conductive pathways to receive electric current from the vehicles for storage and/or to conduct electric current to the vehicles for use in powering the vehicles.

The first vehicle system may travel up the uphill segment **1406**, over the apex **1402**, and down the downhill segment **1408** of the route prior to the second vehicle system. During movement down the downhill segment of the route, the energy generation systems (e.g., dynamic brakes) of the vehicles in the vehicle system may convert the kinetic energy of the vehicles in the first vehicle system into electric current, which is conducted to the wayside energy storage device. During later travel of the second vehicle system up the uphill segment of the route, the vehicles may draw some or all of this current from the wayside energy storage device for use in powering the propulsion systems of the vehicles in the second vehicle system up the uphill segment of the route.

Trip plans for the vehicle systems can be generated for the vehicle systems to transfer energy between vehicles in the different vehicle systems. For example, a first trip plan for a first vehicle system can assign at least some of the vehicles to a group (during a time period of the first trip plan that these vehicles are traveling down the downhill segment) and direct one or more of these vehicles in this group to use dynamic braking to generate electric current. A different, second trip plan for a second vehicle system (traveling over the same route as the first vehicle system, but at a later time) can assign at least some of the vehicles to a group (during a time period of the second trip plan that these vehicles are traveling up the uphill segment) and direct one or more of these vehicles in this group to use (e.g., be powered by) the current supplied from the vehicles generating the current in the first vehicle system. The first and second trip plans of the vehicle systems are logically linked with each other, logically connected with each other, complementary to each other, and/or dependent on each other, as one trip plan (e.g., the first trip plan) directs vehicles to operate in a manner in which another trip plan (e.g., the second trip plan) directs the other vehicles to depend upon.

As another example, vehicles in the same or different vehicle systems may be assigned to groups based on characteristics of different routes. FIG. **17** illustrates vehicle systems **1700**, **1702** traveling on different routes **1704**, **1706** according to another example. The routes **1704**, **1706** may be different routes in that a vehicle or vehicle system may not be able to travel from one route **1704** or **1706** onto the other route **1706** or **1704**, in that the routes are not directly connected with each other (but may be interconnected by one or more other routes), or that the routes **1704**, **1706** are spaced apart from each other by at least a designated distance, such as 10 kilometers, 30 kilometers, 50 kilometers, 100 kilometers, or more.

The vehicle systems **1700**, **1702** can represent one or more of the vehicle systems described herein. The routes **1704**, **1706** can represent one or more of the routes described herein. The vehicles in the vehicle systems **1700**, **1702** may be conductively or inductively coupled with conductive pathways extending along the routes.

In operation, the vehicle system **1700** traveling down a downhill segment of the route **1704** can transfer electric current generated from the energy generation system(s) onboard the vehicle system **1700** (e.g., the dynamic braking systems) to the wayside energy storage device **1502** via the conductive pathways that are conductively or inductively coupled with the wayside energy storage device. During a concurrent or subsequent time period, the wayside energy storage device may transfer some or all of this electric current received from the vehicle system traveling down the downhill segment of the route **1704** to the vehicle system traveling up the uphill segment of the route **1706** to power the propulsion system of one or more vehicles in the vehicle system traveling up the uphill segment of the route.

Optionally, the same vehicle system may both transfer current to and draw the current from the wayside energy storage device. For example, the vehicle systems **1700**, **1702** may be the same vehicle system traveling on the downhill and uphill segments of the routes **1704**, **1706** at different times. The vehicle system may travel down the downhill segment of the route **1704** during a first time period (and transfer electric current to the wayside energy storage device). During a subsequent second time period, the same vehicle system may travel up the uphill segment of the route **1706** and draw at least some of this current from the wayside energy storage device for powering one or more propulsion systems of the vehicle system.

Trip plans can be generated for the vehicle systems to transfer energy between vehicles in the different vehicle systems. For example, a first trip plan for a first vehicle system can assign at least some of the vehicles to a group (during a time period of the first trip plan that these vehicles are traveling down the downhill segment) and direct one or more of these vehicles in this group to use dynamic braking to generate electric current. A different, second trip plan for a second vehicle system (traveling over a different route as the first vehicle system) can assign at least some of the vehicles to a group (during a time period of the second trip plan that these vehicles are traveling up the uphill segment) and direct one or more of these vehicles in this group to use (e.g., be powered by) the current supplied from the vehicles generating the current in the first vehicle system. The first and second trip plans of the vehicle systems are logically linked with each other, logically connected with each other, complementary to each other, and/or dependent on each other, as one trip plan (e.g., the first trip plan) directs vehicles to operate in a manner in which another trip plan (e.g., the second trip plan) directs the other vehicles to depend upon.

In addition to or as an alternate to the trip plans for the different groups of vehicles in the same or different vehicle systems being coupled by providing and receiving electric power from one group to another group (referred to herein as electric power coupling or coupled), the trip plans for the different vehicle groups and/or different vehicle systems may be communicatively coupled (also referred to as information coupling). This type of interdependence of the trip plans can reflect that information obtained by or available onboard the vehicles of one group or one vehicle system is communicated to the vehicles of another group (of the same or different vehicle system) or another, separate vehicle system. This shared information may be used to create and/or modify the trip plan for one or more of the vehicle groups and/or vehicle systems.

For example, the trip plan for a vehicle system can be generated or modified to direct one or more of the vehicles in a leading group of the vehicles in the vehicle system to provide information about characteristics of the route to one or more of the vehicles in a trailing group of the vehicles in the vehicle system (e.g., along a direction of travel of the vehicle system). The trip plan or portion of the trip plan that directs the operational settings of the vehicles in the trailing group may be modified and/or created based on this information that is received. With respect to the example shown in FIG. **14**, one or more of the vehicles may be equipped with a sensor **1416** or sensor array **1416** that detects or otherwise measures characteristics of the route. The sensor may include one or more accelerometers that measure accelerations of the sensor along one or more directions (which can be indicative of grades of the route, curvatures of the route, etc.); one or more optical sensors (e.g., cameras, lidar, infrared light, etc.) that measure distances to the route, curvatures in the route, changes in grade of the route, check for obstructions on the route, and/or check for damage to the route; thermal sensors that measure temperatures of the route (e.g., air temperatures for airborne vehicles, water temperatures for marine vessels, etc.), acoustic sensors (e.g., radar, sonar, etc.) that sense for the presence of obstructions or other objects, speed sensors (e.g., tachometers, accelerometers, etc.) that measure and/or sense moving speed (e.g., rotational speeds of wheels, moving speeds of vehicles, slippage of wheels relative to a surface of the route, etc.), or other sensors.

The information obtained by the sensors of one or more vehicles in the leading group **1408** of the vehicles in FIG. **14** may be representative of route characteristics, and can be communicated to one or more vehicles in the trailing group **1406** of the vehicles in FIG. **14** (e.g., using the communication units described herein). The received route characteristics can be used by the modeling processors, sequencing processors, energy management units, post processing units, and/or effort determination units of one or more vehicles in the trailing group to create and/or modify the operational settings designated by the trip plan for the vehicles in the trailing group.

For example, if the received route characteristics indicate a different route grade and/or curvature than the grade and/or curvature on which the trip plan was based, the trip plan (or at least the portion of the trip plan associated with the vehicles in the trailing group) can be modified or re-created using the grades and/or curvatures indicated by the received route characteristics. As another example, if the received route characteristics indicate undulations in the route (e.g., changing distances between the sensor and the route), then the trip plan (or at least the portion of the trip plan associated with the vehicles in the trailing group) can be modified or re-created to slow down these vehicles during travel over the undulations in the route. In another example, if the received route characteristics indicate damage to the route and/or obstructions on the route, then the trip plan (or at least the portion of the trip plan associated with the vehicles in the trailing group) can be modified or re-created to slow down or stop these vehicles during travel over the damaged portion of the route and/or before reaching the obstructions.

In one embodiment, a system (e.g., a vehicle control system) includes one or more processors configured to assign plural vehicles to different groups in one or more vehicle systems for travel along one or more routes. The one or more processors also are configured to determine trip plans for the different groups of the vehicles. The trip plans designate different operational settings of the vehicles in the different groups at different locations (and/or different times and/or difference distances) along one or more routes during movement of the one or more vehicle systems along the one or more routes. The one or more processors also are configured to modify one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems. The trip plans for the different groups of the vehicles are interdependent upon each other.

Optionally, one or more processors can be configured to determine the trip plans to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to generate electric current during the movement of the vehicles in the first group over a first segment of the one or more routes and directing the vehicles in a second group of the different groups to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group over a second segment of the one or more routes. The one or more processor can be configured to determine the trip plans to direct the vehicles in the first group to generate the electric current during the movement of the vehicles in the first group along a downward grade in first segment of the one or more routes and to direct the vehicles in the second group to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group along an inclined grade in the second segment of the one or more routes. The one or more processors can be configured to assign the vehicles in the first group and the vehicles in the second group in a common vehicle system of the one or more vehicle systems. The one or more processors can be configured to assign the vehicles in the first group in a first vehicle system of the one or more vehicle systems and the vehicles in the second group are included in a separate, second vehicle system of the one or more vehicle systems. The first segment and the second segment of the one or more routes can be different segments of different routes.

In one variation, the one or more processors are configured to determine the trip plans to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to determine and provide one or more characteristics of the one or more routes to the vehicles in a second group of the different groups. The one or more processors can be configured to modify the trip plan of the second group based on the one or more characteristics of the one or more routes determined by the vehicles in the first group. The one or more processors can be configured to assign the vehicles in the first group and the vehicles in the second group in a common vehicle system of the one or more vehicle systems. The one or more processors can be configured to assign the vehicles in the first group in a first vehicle system of the one or more vehicle systems and the vehicles in the second group in a separate, second vehicle system of the one or more vehicle systems. The first segment and the second segment of the one or more routes can be different segments of different routes.

In one embodiment, a method (e.g., for controlling movement of a vehicle system) includes assigning plural vehicles to different groups in one or more vehicle systems for travel along one or more routes and determining trip plans for the different groups of the vehicles. The trip plans designate different operational settings of the vehicles in the different groups at different locations (and/or different times and/or different distances) along one or more routes during movement of the one or more vehicle systems along the one or more routes. The method also includes modifying one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems. The trip plans for the different groups of the vehicles can be interdependent upon each other.

Optionally, the trip plans can be determined to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to generate electric current during the movement of the vehicles in the first group over a first segment of the one or more routes and directing the vehicles in a second group of the different groups to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group over a second segment of the one or more routes. The trip plans can be determined to direct the vehicles in the first group to generate the electric current during the movement of the vehicles in the first group along a downward grade in first segment of the one or more routes and to direct the vehicles in the second group to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group along an inclined grade in the second segment of the one or more routes. The vehicles in the first group and the vehicles in the second group can be included in a common vehicle system of the one or more vehicle systems. Alternatively, vehicles in the first group can be included in a first vehicle system of the one or more vehicle systems and the vehicles in the second group can be included in a separate, second vehicle system of the one or more vehicle systems. The first segment and the second segment of the one or more routes can be different segments of different routes.

In one example, the trip plans can be determined to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to determine and provide one or more characteristics of the one or more routes to the vehicles in a second group of the different groups. The method optionally may also include modifying the trip plan of the second group based on the one or more characteristics of the one or more routes determined by the vehicles in the first group.

Optionally, the vehicles in the first group and the vehicles in the second group can be included in a common vehicle system of the one or more vehicle systems. Alternatively, the vehicles in the first group are included in a first vehicle system of the one or more vehicle systems and the vehicles in the second group can be included in a separate, second vehicle system of the one or more vehicle systems. The first segment and the second segment of the one or more routes can be different segments of different routes.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the inventive subject matter without departing from its scope. While the dimensions and types of materials described herein are intended to define the parameters of the inventive subject matter, they are by no means limiting and are example embodiments. Many other embodiments will be apparent to one of ordinary skill in the art upon reviewing the above description. The scope of the inventive subject matter should, therefore, be determined with reference to the appended clauses, along with the full scope of equivalents to which such clauses are entitled. In the appended clauses, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the following clauses, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following clauses are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. §112(f), unless and until such clause limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

This written description uses examples to disclose several embodiments of the inventive subject matter and also to enable a person of ordinary skill in the art to practice the embodiments of the inventive subject matter, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the inventive subject matter may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the scope of the clauses if they have structural elements that do not differ from the literal language of the clauses, or if they include equivalent structural elements with insubstantial differences from the literal languages of the clauses.

The foregoing description of certain embodiments of the inventive subject matter will be better understood when read in conjunction with the appended drawings. To the extent that the figures illustrate diagrams of the functional blocks of various embodiments, the functional blocks are not necessarily indicative of the division between hardware circuitry. Thus, for example, one or more of the functional blocks (for example, processors or memories) may be implemented in a single piece of hardware (for example, a general purpose signal processor, microcontroller, random access memory, hard disk, and the like). Similarly, the programs may be stand-alone programs, may be incorporated as subroutines in an operating system, may be functions in an installed software package, and the like. The various embodiments are not limited to the arrangements and instrumentality shown in the drawings.

As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to "an embodiment" or "one embodiment" of the inventive subject matter are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising," "including," or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property.

Since certain changes may be made in the above-described systems and methods without departing from the spirit and scope of the inventive subject matter herein involved, it is intended that all of the subject matter of the above description or shown in the accompanying drawings shall be interpreted merely as examples illustrating the inventive concept herein and shall not be construed as limiting the inventive subject matter.

As used herein, a structure, limitation, or element that is "configured to" perform a task or operation is particularly structurally formed, constructed, programmed, or adapted in a manner corresponding to the task or operation. For purposes of clarity and the avoidance of doubt, an object that is merely capable of being modified to perform the task or operation is not "configured to" perform the task or operation as used herein. Instead, the use of "configured to" as used herein denotes structural adaptations or characteristics, programming of the structure or element to perform the corresponding task or operation in a manner that is different from an "off-the-shelf" structure or element that is not programmed to perform the task or operation, and/or denotes structural requirements of any structure, limitation, or element that is described as being "configured to" perform the task or operation.

What is claimed is:

1. A system comprising:

one or more processors configured to assign plural vehicles to different groups in one or more vehicle systems for travel along one or more routes, the one or more processors also configured to determine trip plans for the different groups of the vehicles, wherein the trip plans designate different operational settings of the vehicles in the different groups at different locations along one or more routes during movement of the one or more vehicle systems along the one or more routes,

wherein the one or more processors also are configured to modify one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems, and

wherein the trip plans for the different groups of the vehicles are interdependent upon each other.

2. The system of claim **1**, wherein the one or more processors are configured to determine the trip plans to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to generate electric current during the movement of the vehicles in the first group over a first segment of the one or more routes and directing the vehicles in a second group of the different groups to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group over a second segment of the one or more routes.

3. The system of claim **2**, wherein the one or more processors are configured to determine the trip plans to direct the vehicles in the first group to generate the electric current during the movement of the vehicles in the first group along a downward grade in first segment of the one or more routes and to direct the vehicles in the second group to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group along an inclined grade in the second segment of the one or more routes.

4. The system of claim **2**, wherein the one or more processors are configured to assign the vehicles in the first group and the vehicles in the second group in a common vehicle system of the one or more vehicle systems.

5. The system of claim **2**, wherein the one or more processors are configured to assign the vehicles in the first group in a first vehicle system of the one or more vehicle systems and the vehicles in the second group are included in a separate, second vehicle system of the one or more vehicle systems.

6. The system of claim **2**, wherein the first segment and the second segment of the one or more routes are different segments of different routes.

7. The system of claim **2**, wherein the one or more processors are configured to determine the trip plans to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to determine and provide one or more characteristics of the one or more routes to the vehicles in a second group of the different groups, and

wherein the one or more processors are configured to modify the trip plan of the second group based on the one or more characteristics of the one or more routes determined by the vehicles in the first group.

8. The system of claim **7**, wherein the one or more processors are configured to assign the vehicles in the first group and the vehicles in the second group in a common vehicle system of the one or more vehicle systems.

9. The system of claim **7**, wherein the one or more processors are configured to assign the vehicles in the first group in a first vehicle system of the one or more vehicle systems and the vehicles in the second group in a separate, second vehicle system of the one or more vehicle systems.

10. The system of claim **7**, wherein the first segment and the second segment of the one or more routes are different segments of different routes.

11. A method comprising:

assigning plural vehicles to different groups in one or more vehicle systems for travel along one or more routes;

determining trip plans for the different groups of the vehicles, the trip plans designating different operational settings of the vehicles in the different groups at different locations along one or more routes during movement of the one or more vehicle systems along the one or more routes; and

modifying one or more of the groups to which the vehicles are assigned or the operational settings for the vehicles in one or more of the vehicle systems based on a movement parameter of one or more of the vehicle systems,

wherein the trip plans for the different groups of the vehicles are interdependent upon each other.

12. The method of claim **11**, wherein the trip plans are determined to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to generate electric current during the movement of the vehicles in the first group over a first segment of the one or more routes and directing the vehicles in a second group of the different groups to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group over a second segment of the one or more routes.

13. The method of claim **12**, wherein the trip plans are determined to direct the vehicles in the first group to generate the electric current during the movement of the vehicles in the first group along a downward grade in first segment of the one or more routes and to direct the vehicles in the second group to receive and be at least partially powered by the electric current generated by the vehicles in the first group during the movement of the vehicles in the second group along an inclined grade in the second segment of the one or more routes.

14. The method of claim **12**, wherein the vehicles in the first group and the vehicles in the second group are included in a common vehicle system of the one or more vehicle systems.

15. The method of claim **12**, wherein the vehicles in the first group are included in a first vehicle system of the one or more vehicle systems and the vehicles in the second group are included in a separate, second vehicle system of the one or more vehicle systems.

16. The method of claim **12**, wherein the first segment and the second segment of the one or more routes are different segments of different routes.

17. The method of claim **11**, wherein the trip plans are determined to be interdependent upon each other by the trip plans directing the vehicles in a first group of the different groups to determine and provide one or more characteristics of the one or more routes to the vehicles in a second group of the different groups, and further comprising modifying the trip plan of the second group based on the one or more characteristics of the one or more routes determined by the vehicles in the first group.

18. The method of claim **17**, wherein the vehicles in the first group and the vehicles in the second group are included in a common vehicle system of the one or more vehicle systems.

19. The method of claim **17**, wherein the vehicles in the first group are included in a first vehicle system of the one or more vehicle systems and the vehicles in the second group are included in a separate, second vehicle system of the one or more vehicle systems.

20. The method of claim **12**, wherein the first segment and the second segment of the one or more routes are different segments of different routes.

* * * * *